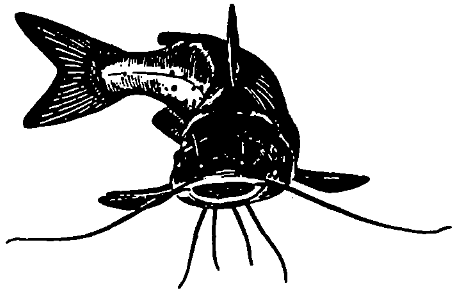
CHANNEL CATFISH OF THE BUFFALO NATIONAL RIVER, ARKANSAS: POPULATION ABUNDANCE, REPRODUCTIVE OUTPUT, AND ASSESSMENT OF STOCKING CATCHABLE SIZE FISH



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Master of Science

By

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INTRODUCTION

Prior to the 1930's, supplemental stocking of various fish species was a standard fisheries management tool utilized by state game and fish agencies. If fishing was considered to be poor, state or federal agencies were requested to stock additional fish, under the assumption that natural reproduction and recruitment were unable to maintain an adequate population. With development of methods for marking individual fish came evidence that stocking additional fish was ineffective when the population had reached carrying capacity (Bennett 1970). However, fish stocking is still viewed by some states (Keith 1986), and by many anglers, as the answer to many fishery problems (Smith and Reeves 1986). There is also increasing public pressure for supplemental stocking due to a common assumption that stocking additional fish will improve angler return (Loska 1982). By promoting hatchery technology and giving hatchery tours, fisheries scientists have misled the public into thinking that hatcheries and stocking programs are necessary and can compensate for factors such as habitat loss (Hilborn 1992). Thus, stocking to enhance cool-water and warm-water fisheries remains a well established and popular management tool (Noble 1986). For example, by 1986 forty-three of fifty states stocked warm-water fish species and the reasons given for these stocking programs were non-reproduction of stocked species, inadequate spawning due to reduced habitat, or high exploitation due to extreme angler pressure (Smith and Reeves 1986).

Although basic pre-stocking criteria such as potential impacts to resident biota, suitability of stocking habitat, and social and economic considerations have been outlined (Murphy and Kelso 1986) and subsequently investigated for many salmonid species, only recent refinements in salmonid stocking practices have included actual criteria for assessing stocking needs (Potter and Barton 1986). It may be necessary to supplementally stock some waters that support existing wild trout populations to compensate for poor recruitment, overharvest, or loss of habitat, but stocking criteria for such waters must still be established (Wydoski 1986). For most game fishes, especially warm-water game species, techniques for assessment of stocking needs in response to inadequate reproduction or recruitment have not been adequately developed. Recent refinement of sampling techniques for larval and early-juvenile fishes may allow early detection of weak year-classes (Noble 1986). Thus, for some species it may have become possible to predict or detect the need for supplemental stocking early enough for management practices to be implemented, if such needs can be related to production.

In the United States, channel catfish (Ictalurus punctatus) culture and management for game fish purposes is second in importance only to that of largemouth bass (Micropterus salmoides), and catfish stocking programs currently exist in 35 states (Smith and Reeves 1986). Stocking of catchable size channel catfish is popular among natural resource agencies because of immediate contributions to the angler's creel (Broach 1968). In spite of this popularity, relatively little information exists on pre-stocking guidelines or techniques to assess stocking needs for channel catfish within a particular body of water or in response to yearly variation in abundance through natural reproduction and recruitment. Such information is important because criteria for implementation of any management program, such as supplemental stocking, must be that there is some benefit to be gained (Noble 1986).

A second criteria for evaluation of a supplemental stocking program is to determine the fate of the hatchery-reared fish following stocking. Review of the literature indicates a lack of information on post-stocking dispersal, food habits, growth, survival, and impact on the resident fish community, especially for hatchery-reared channel catfish released into flowing waters. Information on these parameters is crucial for effective evaluation of current and future channel catfish stocking programs.

In Arkansas, more than one million channel catfish, mostly of catchable size, are stocked annually in public and private waters (Arkansas Game and Fish Commission stocking records). Most natural resource agencies that employ channel catfish stocking programs utilize catchable size fish because of higher survival rates and cost-efficient angler returns (Mestl 1983; Spinelli, Whiteside, and Huffman 1985; Storck and Newman 1988). Stocking records for the Buffalo River, Arkansas indicate more than 1.5 million fish of various species have been stocked in the river and its tributaries since 1942, with channel catfish being the most commonly stocked fish in the river (Table 1). The Buffalo River illustrates an excellent example of how a stocking program has been implemented for over 50 years with little or no information on the need for these stockings, or on the fate (survival, growth, angler harvest) of the stocked fish following release.

The objectives of this study were to (1) develop pre-stocking criteria to identify the need for supplemental channel catfish stocking in warm-water streams, and (2) assess the fate of hatchery-reared fish following release in the Buffalo River. The criteria for supplemental stocking of channel catfish was developed by assessing reproductive output and recruitment of the existing catfish population in the Buffalo River. Reproductive output of channel catfish was also assessed among several similar type Ozark streams in northwest Arkansas. The fate of channel catfish stocked in the Buffalo River was evaluated based on post-stocking dispersal, food habits, growth, survival, and relative contribution of the hatchery-reared fish to the existing population. In addition, this study provides basic biological data on population characteristics and early life history parameters for channel catfish inhabiting clear-water Ozark streams.

Table 1. Numbers of fish stocked in the Buffalo River and a major tributary, the Little Buffalo River, as reported in Arkansas Game and Fish Commission stocking records. Species were stocked at various locations in both rivers from 1942 to present[a].

Species	Buffalo River	Little Buffalo River	Total
channel catfish	304,879	94,843	399,722
smallmouth bass	171,250	63,400	234,650
largemouth bass	174,450	27,850	202,300
rock bass	55,600	950	56,550
bream[b]	197,300	159,700	357,000
green sunfish	124,000	——	124,000
black or white crappie	39,900	10,100	50,000
bullheads	6,000	——	6,000
Totals	1,073,379	355,593	1,430,222

a Total does not include fish stocked in other Buffalo River tributaries

b Bream includes redear sunfish, bluegills, and Lepomis hybrids

DESCRIPTION OF STUDY AREAS

The abundance of young-of-the-year (YOY) channel catfish was determined for the Illinois, Mulberry, Kings, and Buffalo rivers of northwestern Arkansas (Figure 1). All four rivers originate in the Boston Mountains and are typical clear-water Ozark streams characterized by long pools separated by short riffles. The substrate is primarily gravel and rubble in the headwater sections; rubble, boulder, and bedrock in the middle reaches; and some deposits of sand and silt in the lower reaches. Land use in the watersheds of the Kings, Mulberry, and Illinois rivers consists of agriculture and forestry. The Buffalo River flows through National Park Service (NPS) land and has been managed by NPS since 1972. The Kings, Illinois, Mulberry, and Buffalo rivers are free-flowing prior to their confluence with Table Rock Reservoir, Tenkiller Reservoir, Arkansas River, and White River tail-waters below Bull Shoals Dam, respectively (Figure 1).

Discharge of the four rivers varies seasonally, with a general pattern of high flow during spring and early summer and low flow in late summer and autumn, but local storm events can produce spates in any season. Low discharge during late summer and autumn results in intermittent flows and isolated pools in headwater reaches. Average annual discharge for Kings River is 12 m^3/s and ranges from 0.01 to 35.3 m^3/s (USGS 1988a). The Mulberry River has slightly higher gradient (4.3 m/km) than the other three rivers; average annual discharge is 15.3 m^3/s (USGS 1988b). Average annual discharge for the Illinois River is 22.2 m^3/s and ranges from 0.1 to 538.0 m^3/s (USGS 1988a). Average annual discharge reported for the middle reach of the Buffalo River (the only data available) is 25.8 m^3/s and ranges from 0.04 to 555.0 m^3/s (USGS 1988a).

Because of heavy angler pressure and low productivity typical of clear-water Ozark streams (Allen Carter, Arkansas Game and Fish Commission [AGFC], personal communication), AGFC annually stocks each of the four rivers with 500 to 4,000 catchable-size (>280 mm) channel catfish (Broach 1967). These rivers have been supplementally stocked with various fish species since the mid-1940's, but stockings during the past 10 to 15 years have consisted exclusively of catchable-size channel catfish (AGFC records).

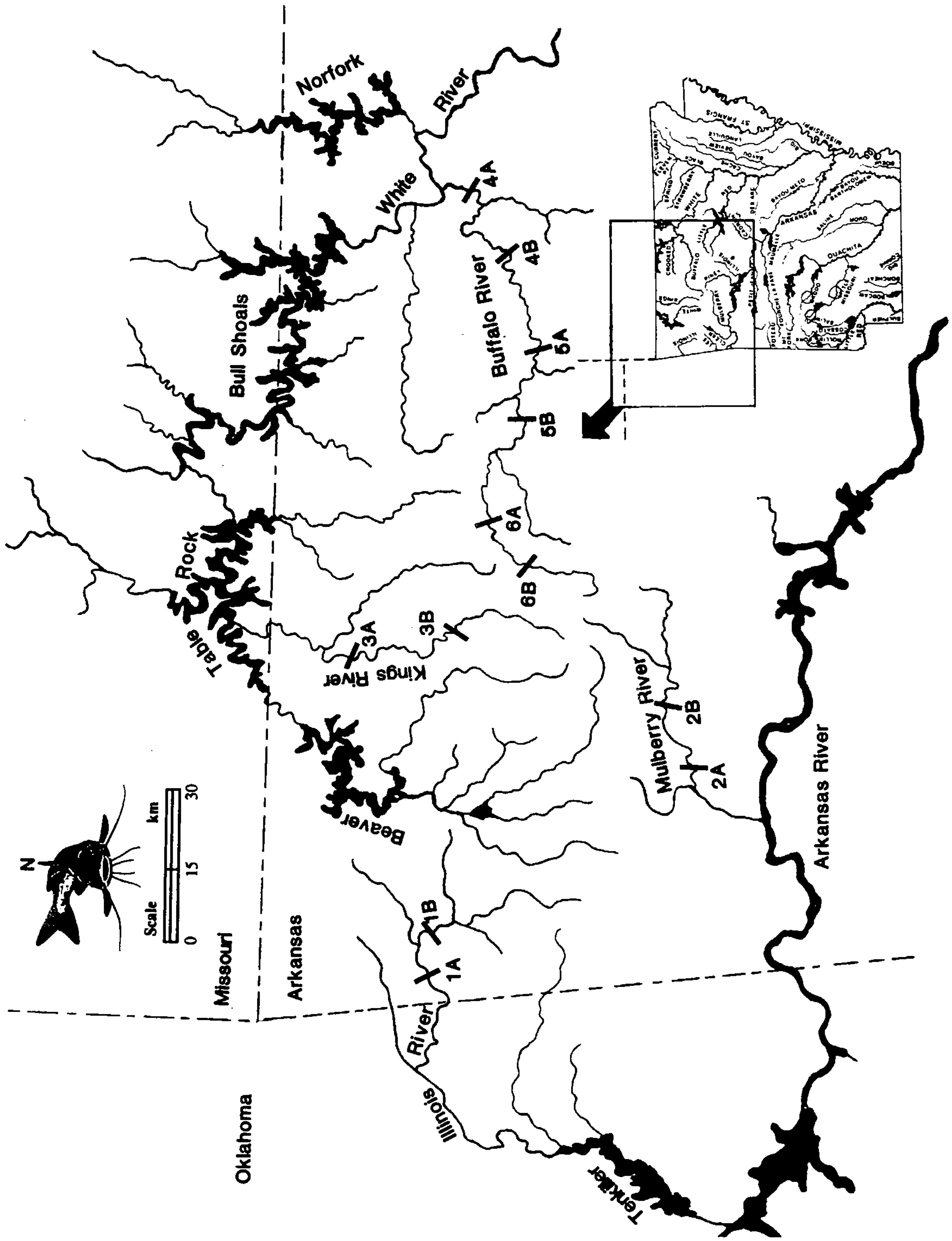
METHODS

Reproductive Output and Recruitment

To evaluate stocking needs for channel catfish in the Buffalo River, reproductive output and recruitment into the existing catchable population were assessed. Since it has been shown that larval channel catfish occur in the nocturnal drift of streams (Armstrong 1984; Floyd, Hoyt, and Timbrook 1984; Muth and Schmulbach 1984), larval drift nets were used to assess the abundance of YOY channel catfish, which represented an index for reproductive output. Successful reproduction and recruitment from previous years were determined from relative age class abundance within the existing channel catfish population of the Buffalo River.

Larval Drift: Sampling sites were selected from three reaches of the Buffalo River (upper, middle, lower) and from middle reaches of the Kings, Mulberry, and Illinois rivers, for a total of six sites. Sampling sites in each river consisted of two sampling stations, a lower site (A) and an upper site (B) about 15 km apart (Figure 1). Sampling stations were locted at the heads of riffles just downstream from large pools. Young-of-year channel catfish were collected with rectangular drift nets (net opening 20 x 30 cm; total net length = 1.2 m; nylon mesh size = 0.5 mm) randomly positioned across a transect at the head of a riffle. Nets were anchored in the riffle, with the 20-cm side resting on the substrate, by driving two steel rods through brackets on each side of the net into the substrate. Four nets were fished at each sampling station, and both localities (A and B) were fished simultaneously on each sampling date. Sampling was initiated 15 June 1991 and continued until each station had been sampled four times (4 nets $\times$ 2 stations $\times$ 4 sampling dates = 32 net samples/river or reach). The sampling schedule for the six sites was divided into four, six-day intervals, with each site being randomly assigned to a sampling day within each of the four intervals. In designing the model used for statistical

Figure 1. Study sites for evaluation of young-of-year channel catfish abundance in the Illinois, Mulberry, Kings, and Buffalo rivers of northwestern Arkansas. "A" is the downstream sampling station and "B" is the upstream station.



Oklahoma
Missouri
Arkansas
N
Scale
km
0
15
30
Illinois
River
Tenkiller
1A
1B
Beaver
Table
Rock
Kings River
3A
3B
Mulberry River
2A
2B
Arkansas River
6A
6B
5A
5B
Buffalo River
4A
4B
Bull Shoals
White
River
Norfork

analysis, the four time intervals were blocked within the model and the sampling stations were nested within each river (nested block design).

Sampling was initiated at sunset and continued until sunrise, with a total sampling time of about eight hours. This nocturnal sampling regime was chosen because Armstrong (1984) reported channel catfish drift occurs only at night, with a bimodal peak three hours after sunset and three hours before sunrise. Nets were emptied at midnight and sunrise unless extensive drifting debris reduced net efficiency, in which case nets were emptied hourly. Large plant materials (e.g., leaves and branches) were rinsed and discarded, and all remaining net contents were preserved in 5% formalin solution buffered with borax (Taylor 1977) for later separation and identification in the laboratory. All YOY channel catfish caught in the drift nets were identified, enumerated, and a subsample of ten fish per net was measured for total length [TL] to the nearest 0.5 mm.

Water velocity (measured with a torpedo-type flowmeter) and depth were measured at each net to allow standardization of water volume sampled by individual nets. Based on volume of water sampled, the number of YOY channel catfish collected from each net (catch) was adjusted to represent an equal sampling effort, using the following equation: catch $\times$ mean depth of all nets (23.0 cm)/depth net was fished $\times$ mean water velocity through all nets (25.0 cm/s)/water velocity passing through net. Total catch per net thus represented the approximate number of YOY channel catfish collected per 330.0 m^3 of water sampled. Additional variables measured at the beginning and end of each sampling interval included water temperature, turbidity, and discharge. The lowest site (Site 4; Figure 1) of the Buffalo River was used for comparisons among rivers.

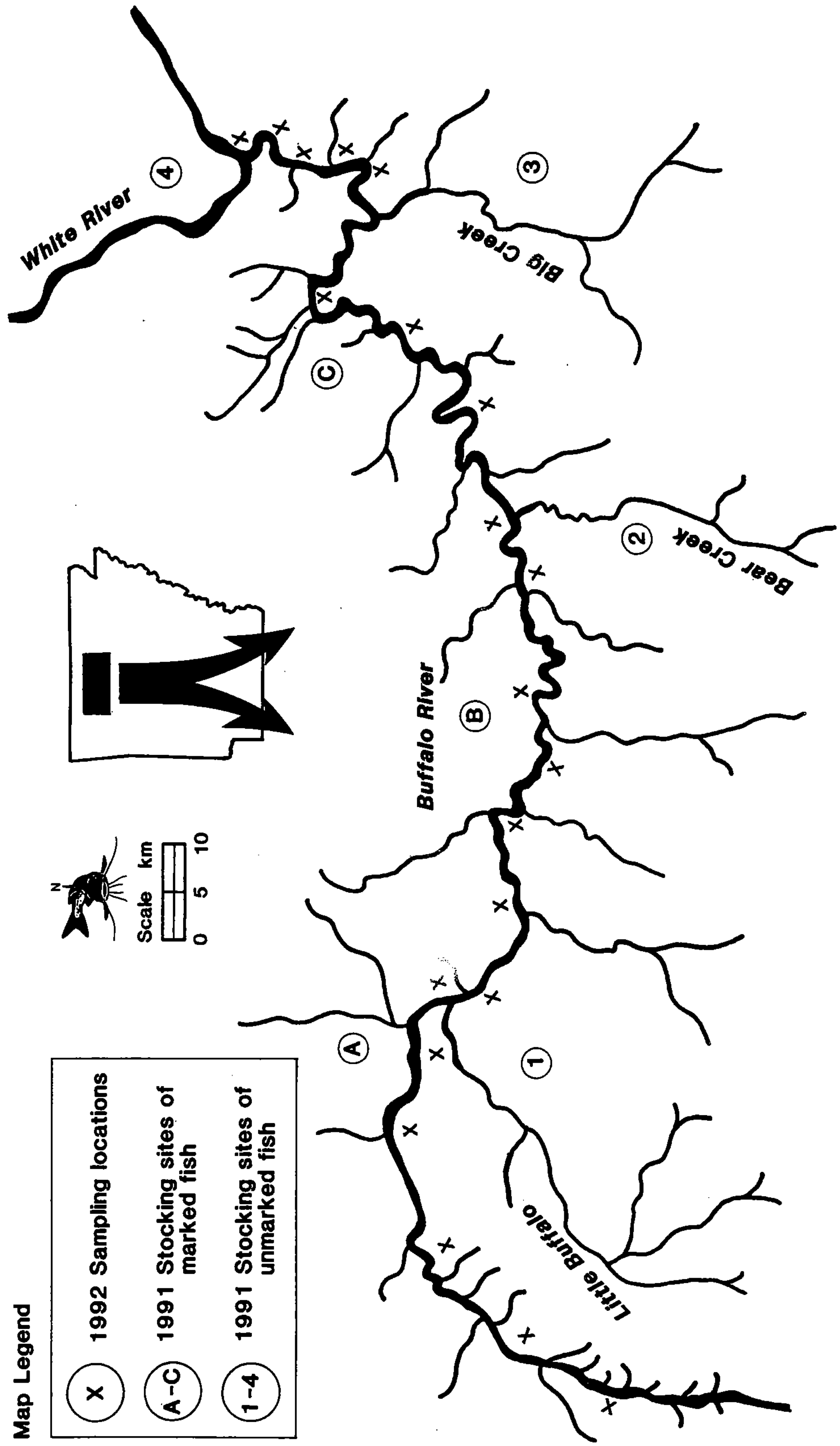
Differences in the abundance of YOY channel catfish and physical variables measured among and within river sites were compared by analysis of variance (ANOVA) using the Statistical Analysis System (SAS Institute 1988). If a significant difference was found ($P < 0.05$), the ANOVA was followed by Bonferroni's Multiple Range Test to identify river sites that differed from one another. To satisfy assumptions of the statistical analysis (i.e., constant variance of catches among rivers and normal distribution of residuals), total catch/net was transformed using a standard ln(x + 1) transformation (Box and Cox 1964). Regression analysis was used to identify any potential relationships between water depth or velocity and catch rates of YOY channel catfish from individual drift nets.

Adult Age Structure in the Buffalo River: Abundance and age structure of the adult channel catfish population in the Buffalo River was evalulated to determine the level of natural reproduction and recruitment from previous years. Adult channel catfish were collected during August and September 1991 and during July and August 1992 with baited (pressed soybean cake) hoop nets, trotlines, and electrofishing. Hoop nets were of two designs: 1) 1.9-cm web (bar measure), double finger throated, with six 0.6-m diameter hoops, and 2) 3.2-cm web, double finger throated, with seven 1.1-m diameter hoops. One large net and one small net were fished in tandem continuously for 48 h; one net fished for a 24 h period represented one net-day of effort. Trotlines were constructed of 50, size 1/0 forged hooks spaced at 1-m intervals on a 30-cm leader. Trotlines were set in shallow pools along shoreline areas prior to sunset and fished until sunrise; a single overnight set represented one trotline night of effort. Electrofishing was conducted using a standard pulsed DC boat shocker. All channel catfish captured were weighed (mm), measured (TL), and a pectoral spine was removed for age determination before being returned alive to the river. In the laboratory, spines were cut into thin cross-sections with a Dremel® moto tool and aged under a dissecting microscope as described by Sneed (1951) and Marzolf (1955).

Post-Stocking Assessment

Arkansas Game and Fish Commission annually stocks 3,000 to 4,000 catchable size channel catfish in the Buffalo River (AGFC records; Table 2). To evaluate post-stocking dispersal, food habits, growth, and contribution of the stocked fish to the existing

Figure 2. Map of the Buffalo River showing 1991 stocking sites and 1992 sampling locations.


Map Legend
X 1992 Sampling locations
A-C 1991 Stocking sites of marked fish
1-4 1991 Stocking sites of unmarked fish
Scale km
0 5 10
N
White River
Big Creek
Bear Creek
Buffalo River
Little Buffalo
A
B
C
1
2
3
4

population in the Buffalo River, three stocking sites (A-C) were selected at pool habitats near the upper, middle, and lower reaches of the river, and 21 netting locations (X) were selected from various reaches above and below each stocking site (Figure 2). Arkansas Game and Fish Commission records indicate that annual fall stockings of 300 to 1,500 channel catfish are also made in several tributaries to the Buffalo River (Sites 1-4; Figure 2).

Dispersal: Channel catfish were obtained from the AGFC net pen rearing facility on Bull Shoals Reservoir on 25 September, 1991. Fish were marked by removing either the left pelvic fin, adipose fin, or right pelvic fin, corresponding to stocking sites A, B, or C, respectively (Figure 2), and stocked in the Buffalo River the same day at the rate of 1,200 fish per site. Water temperature of the net pens, stocking trucks, and Buffalo River were from 19 to 21°C. A subsample of 110 fish had an initial mean (±SD) length and weight of 270 (±3.5) mm and 172 (±77.7) g, respectively, with an average condition factor, $K=10^5$(weight, g)/(total length, mm)^3, of 0.81 (±0.10).

During July and August 1992 baited (pressed soybean cake) hoop-nets were deployed at each of the 21 sampling sites located throughout the Buffalo River, above and below each of the three stocking sites (Figure 2). At each sampling site, one large hoop-net and one small hoop-net (net dimensions previously described) were fished in tandem continuously for 48 hours. All channel catfish collected were inspected for fin clips, measured for total length (TL), weighed, and a pectoral spine was removed from all non-marked channel catfish prior to release for aging and to identify catfish stocked in previous years. Using pectoral spine cross-sections, channel catfish stocked in previous years were identified by the presence of wide increments of growth prior to formation of the first and second annuli (corresponding to net pen growth), followed by relatively narrower increments of growth prior to formation of all subsequent annuli (see Appendix A for a more detailed description of the technique used to identify non-marked hatchery fish).

Average dispersal distance (km) was a measure of the distance between recapture locations and the original stocking sites (Figure 2). Differences in dispersal distance among marked catfish from each of the three stocking sites were compared by analysis of variance (ANOVA) using the Statistical Analysis System (SAS Institute 1988). If a significant difference was found ($P < 0.05$), the ANOVA was followed by Bonferroni's Multiple Range Test to identify individual differences in dispersal distance among catfish released at the three stocking sites. Linear regression analysis was used to test relationships between fish size and average dispersal distance.

Food Habits: Channel catfish sampled for diet analysis were collected with pole and line or by electrofishing. During October and November 1991, stomach and intestinal samples were collected for diet analysis from 25 marked catfish (4 to 6 weeks post-stocking) and from 12 non-marked catfish determined to be of hatchery origin (1 to 3 years post-stocking; see Appendix A). Stomach samples were obtained from the 12 non-marked catfish in order to verify that resident channel catfish in the Buffalo River were actively feeding during October and November. During July and August 1992, stomach and intestinal samples were collected from an additional 40 marked catfish (10-11 months post-stocking). Following removal, the stomachs and intestines were preserved in 10% formalin for later analysis in the laboratory. Stomach and intestinal contents were separated into five categories: (1) aquatic invertebrates or insects in aquatic life stage (invert/insect), (2) terrestrial insects, (3) fish, (4) plants, and (5) miscellaneous items such as unidentifiable insect or animal remains (Bailey and Harrison 1948). Percent occurrence, percent total volume (water displacement), and relative importance were determined for the five categories prior to further identification. Organisms from each of the five categories were then identified to the most reasonable taxon possible. Relative importance was a measure of the percent occurrence plus the percent total volume of a particular food category or taxon present in the diet (Baily and Harrison

1948). Differences in stomach and intestinal contents between fish at 4-6 weeks and 10-11 months post-stocking were compared using a student t-test analysis.

Growth: Average growth of hatchery-reared channel catfish following release in the Buffalo River was determined by subtracting the mean length (mm) and weight (g) for all marked fish recorded at the time of recapture during July and August 1992 (n=95) from the initial mean length and weight observed for hatchery-reared fish prior to stocking (n=110). Back-calculated growth rates of channel catfish identified as stocked fish from previous years were not determined because a significant regression ($P < 0.05$) did not exist between spine radius and fish size (Ricker 1975) for hatchery-reared catfish of different ages (i.e., initial fish size at stocking was not consistent among years). However, average overall growth of catfish stocked in previous years (1986 through 1991—ages 3-6; stocking origin verified from pectoral spine cross-sections) was determined by subtracting mean length and weight measured at the time of stocking (obtained from AGFC hatchery records) from the mean length and weight observed for each year-class at the time of recapture in 1992 (e.g., the mean size of channel catfish stocked in 1987 was subtracted from mean size of age 6 catfish collected in 1992).

Proportion of Stocked Fish in the Population: The relative contribution of the 3,600 hatchery-reared channel catfish stocked in the Buffalo River in 1991 was determined from the ratio of marked to non-marked catfish present in the population at the time of sampling during July and August 1992. In addition, pectoral spines collected from all non-marked channel catfish were cross-sectioned and analyzed to identify any non-marked hatchery-reared catfish within the population (see Appendix A for discussion of this procedure) so that the total contribution of catfish stocked in the Buffalo River prior to 1991 could be determined.

Mortality and Survival: Average annual mortality of catfish stocked in the Buffalo River was determined by simple linear regression, where log frequencies were plotted against age directly (Ricker 1975). This procedure requires the assumption of

Table 2. Total numbers of channel catfish stocked in the Buffalo River drainage from 1986 to 1991. These stockings are sources of stocked channel catfish collected in hoop net-samples from the Buffalo River during 1991 and 1992.

	Year Stocked					
Location	1986	1987	1988	1989	1990	1991
Buffalo River	2,320	3,152	0	0	0	3,600[a]
Little Buffalo	500	306	1,187	500	500[b]	1,250
White River[c]	0	0	1,551	2,010	602	605
Crooked Creek[d]	2,200	2,155	2,065	1,492	1,615	1,575
Big Creek	0	0	520	0	344	475
Bear Creek	0	0	0	504	551	535
Total	5,020	5,613	5,323	4,506	3,612	8,040

[a] Not included in mortality estimate

[b] Marked using adipose fin clip

[c] Stocked at Buffalo City access, 300 m above the mouth of the Buffalo River

[d] Crooked Creek flows into White River 5 km above the mouth of the Buffalo River

constant recruitment among years (Ricker 1975), thus, marked hatchery fish stocked in 1991 were not included in the estimate because direct stockings of channel catfish were not made in the Buffalo River from 1988 through 1990. This provided a more reliable mortality estimate since a constant number of catfish have been stocked in the Buffalo River and its tributaries from 1986 to 1991 (Table 2).

Population Estimate: An estimate of the channel catfish population in the Buffalo River was calculated using the 3,575 fin-clipped hatchery-reared fish (25 were removed for stomach samples 4-6 weeks following stocking) as the marked fish in a Peterson type estimate (Ricker 1975). In this method, the estimated population (P) = number of fish marked (M) X recapture sample size (C) + number of marked fish recaptured (R). A 95% confidence interval for the point estimate was determined using a binomial approximation table (Ricker 1975). Peven and Hays 1989, and Hepworth et al. 1991 have also used marked hatchery fish for population or abundance estimates. They concluded that estimates using hatchery fish are reliable if the following assumptions are met: (1) marked (hatchery) fish suffer the same mortality as unmarked fish; (2) marked and unmarked fish are equally vulnerable to angler harvest; (3) marked fish do not lose their marks; (4) marked fish become randomly mixed with unmarked fish; (5) all marks are recognized at the time of recovery; and (6) there is only a negligible amount of recruitment to the catchable population during the time of recovery (Ricker 1975).

RESULTS

Reproductive output and recruitment

Larval Drift: A total of 3,300 YOY channel catfish was collected from 192 drift net samples. Mean (±SD) total length of a subsample of 640 YOY channel catfish was 16.8 ± 1.0 mm (Figure 3). The length of these fish was remarkably consistent over the eight-week sampling period (15 June to 20 July) and among the four rivers sampled (Table 3). Because of this consistent small size, all YOY channel catfish collected were believed to be between 5 and 10 days old, and to have recently dispersed from nesting areas (Saksena 1961). The highest number of YOY channel catfish was collected from the Illinois River (n=2,007), and the lowest number (n=0) was collected from the uppermost Buffalo River site. Adjusted mean number of YOY channel catfish caught/drift net varied among rivers, ranging from 56.7 fish for the Illinois River to 1.0 fish for the lower site of Buffalo River (Table 3). Analysis of catches among the four rivers showed significantly ($P < 0.01$) lower mean catches from the Buffalo River when compared with the Kings, Mulberry, and Illinois rivers (Table 3). The Illinois River also had significantly ($P < 0.01$) higher catch rates than did the Kings and Mulberry rivers.

The presence of YOY channel catfish from 15 June through 22 July in all four rivers indicated a protracted spawning period, with generally lower catches later in the season, except for the Illinois River which had a bimodal peak of YOY catch rates. Catches of YOY channel catfish in the Illinois, Mulberry, and Kings rivers were consistently higher than in the Buffalo River; however, catches from all rivers varied spatially and temporally (Figure 4). The Kings River had the highest variation among sampling stations because no YOY channel catfish were caught at the upper station (3B), while over 800 YOY catfish were collected at the lower station (3A). The riffle of the upper Kings River sampling station became intermittent during the final sampling period.

Although catches of YOY channel catfish within the Buffalo River were sparse, spatial patterns of catches in the three reaches indicated a longitudinal increase in abundance from upper to lower river sites. Average catch from the lowest site on the Buffalo River was significantly ($P < 0.01$) higher than catches from sites on the upper or middle reaches of the river (Table 4). No YOY channel catfish were caught from the uppermost three sampling stations (5B, 6A, 6B; Figure 1) of the Buffalo River.

Differences in abundance of YOY channel catfish among the four rivers appeared to be related to differences in total discharge (river size), with the exception of the Buffalo River which had the highest discharge (Figure 5) and lowest abundance of YOY channel catfish (Table 3). This relation did exist, however, among the three reaches of Buffalo

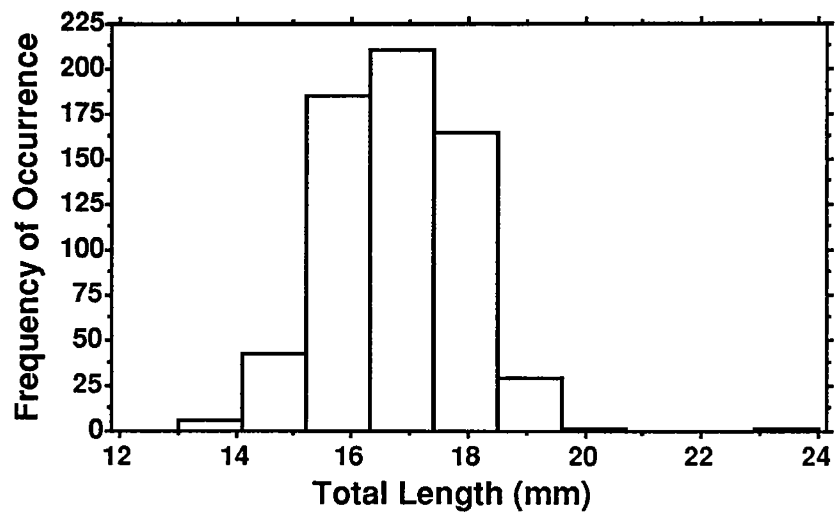
River, where YOY channel catfish were increasingly more abundant (Table 4) in lower, higher-discharge sites (Figure 5). Differences in YOY channel catfish abundance among rivers did not appear to be related to water temperature or turbidity. Water temperatures among the four rivers did not differ significantly, as all had mean temperatures between 25 and 29°C (Table 3). Turbidity also did not differ significantly, although turbidity levels for the Buffalo River were consistently lower than the other three rivers (Table 3).

Variation in catch rates of YOY channel catfish for individual drift nets was not significantly correlated with water depth or velocity for any of the four rivers ($r^2 < 0.20$ for all, but one river), and there was no relation between catch rates and lateral position of drift nets set across the riffle. This showed there was no apparent preferences for current, depth, or lateral habitat in the river channel, and YOY channel catfish in the size range collected (14 to 19 mm) did not avoid drift nets placed in areas of the riffle with lower velocity.

Adult Age Structure in the Buffalo River: In 1991, only 44 adult channel catfish were collected from more than 40 hoop net-days and 10 trotline nights of effort in the Buffalo River. In 1992, 235 catfish were collected from about 80 hoop net-days of effort. More than 86% of adult channel catfish were collected from the lower river, near stations 4A and 4B, despite lower sampling effort in this reach. Overall hoop net catch-per-unit-effort (CPUE) for all reaches of the Buffalo River was 0.48 channel catfish/net-day in 1991 and 2.25/net-day in 1992. Overall CPUE for trotlines in 1991 was 0.70 channel catfish/trotline-night. No adult channel catfish were collected from reaches above Station 6A (Figure 1).

Channel catfish age distribution ranged from age 2 through 12, however, more than 51% and 74% of the channel catfish collected in 1991 and 1992, respectively, were age 2 or 3 (Figure 6). In a typical population structure, the age distribution of channel catfish observed in the Buffalo River would represent successful reproduction and recruitment

Figure 3. Combined length frequency distribution of YOY channel catfish collected in drift nets from the Illinois, Mulberry, Kings, and Buffalo rivers from 15 June to 22 July 1991.



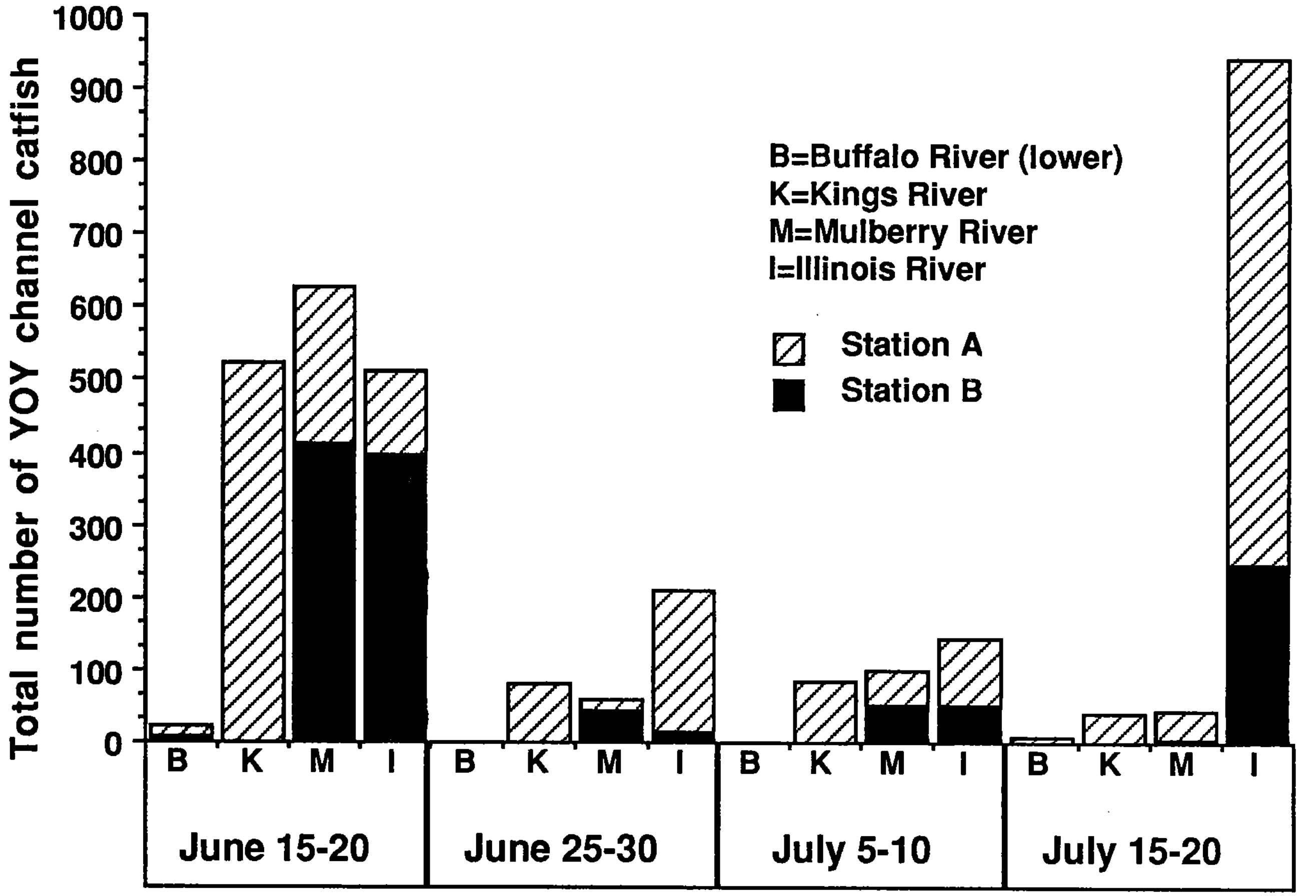
Frequency of Occurrence
0
25
50
75
100
125
150
175
200
225
12
14
16
18
20
22
24
Total Length (mm)

Table 3. Comparison of mean (±SE) number of YOY channel catfish/drift net, fish length, water temperature, and turbidity among the Kings, Mulberry, Illinois, and Buffalo rivers. Values in each row without a letter in common are significantly different ($P < 0.01$).[a]

Variable	River: Buffalo	Kings	Mulberry	Illinois
Adjusted average catch/net	1.0	26.1	25.9	56.7
	(±0.4)	(±9.0)	(±9.9)	(±13.0)
Transformed ln(x + 1) average catch/net	0.4^{x}	1.9^{y}	2.3^{y}	3.4^{z}
	(±0.1)	(±0.3)	(±0.3)	(±0.2)
Mean total length (mm)	17.0	17.1	16.3	16.9
	(±1.5)	(±0.8)	(±1.0)	(±1.0)
Mean water temperature (°C)	29.2	25.7	27.1	25.3
	(±0.3)	(±0.4)	(±0.3)	(±0.2)
Mean turbidity (ppm)	0.8	2.6	4.8	3.9
	(±0.2)	(±1.3)	(±3.1)	(±0.4)

[a] Comparisons were not made between adjusted average catch/net due to violations of statistical assumptions (unequal variance among sites).

Figure 4. Total adjusted number of YOY channel catfish collected in drift nets from sampling stations on the lower Buffalo, Kings, Mulberry, and Illinois rivers during four time intervals.



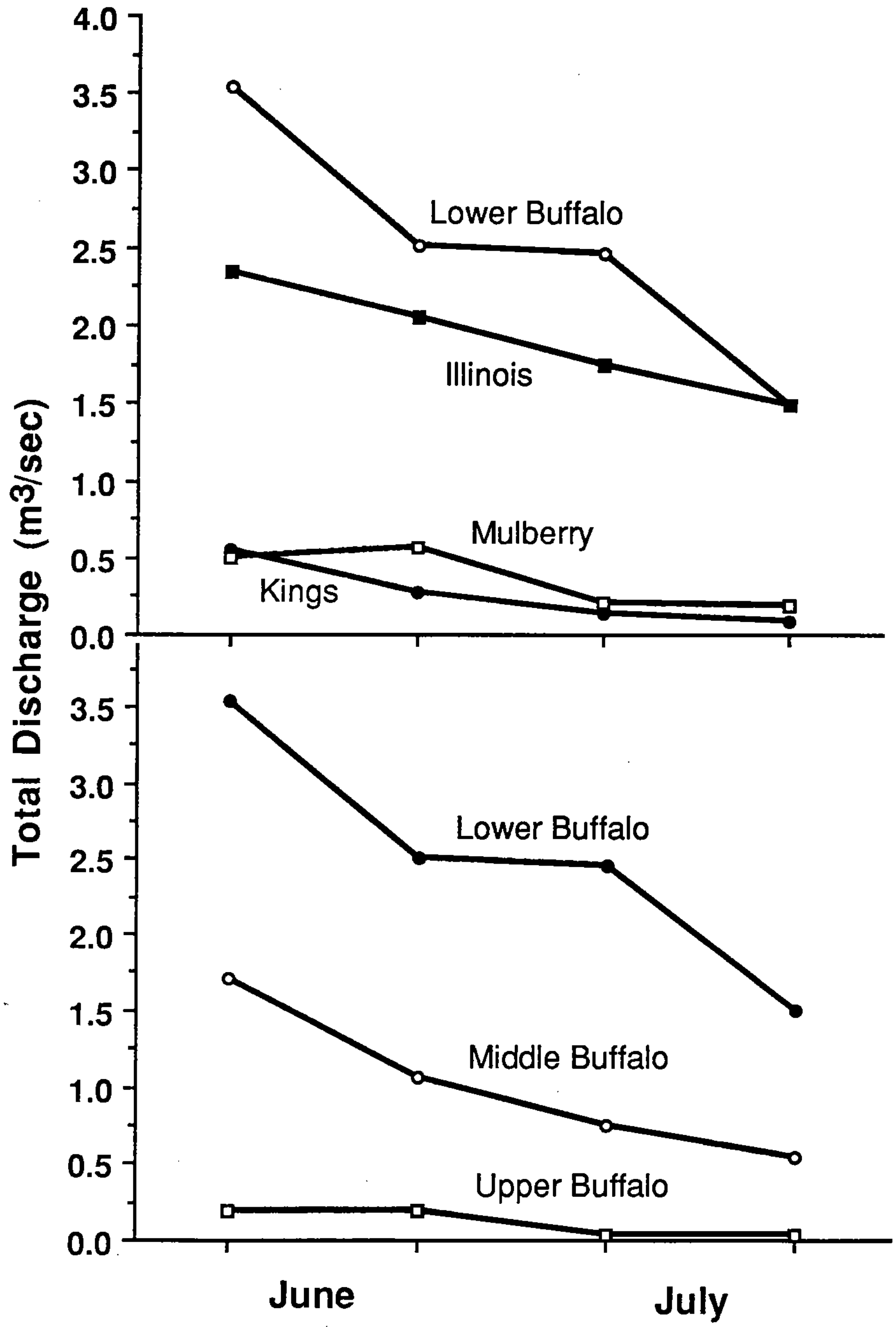
Total number of YOY channel catfish
1000
900
800
700
600
500
400
300
200
100
0
B=Buffalo River (lower)
K=Kings River
M=Mulberry River
I=Illinois River
Station A
Station B
B K M I
June 15-20
B K M I
June 25-30
B K M I
July 5-10
B K M I
July 15-20

Table 4. Comparison of mean (±SE) number of YOY channel catfish/drift net, water temperature, and turbidity among study sites on the upper, middle, and lower reaches of the Buffalo River. Values in each row without a letter in common are significantly different ($P < 0.01$).[a]

	Buffalo River Sampling Site		
Variable	Upper	Middle	Lower
Adjusted average catch/net	0.0	0.2	1.0
	(±0.0)	(±0.1)	(±0.4)
Transformed ln(x +1) average catch/net	0.0[y]	0.1[y]	0.4[z]
	(±0.0)	(±0.01)	(±0.01)
Mean water temperature (°C)	26.3	27.9	29.2
	(±0.3)	(±0.2)	(±0.3)
Mean turbidity (ppm)	0.5	0.5	0.8
	(±0.1)	(±0.1)	(±0.1)

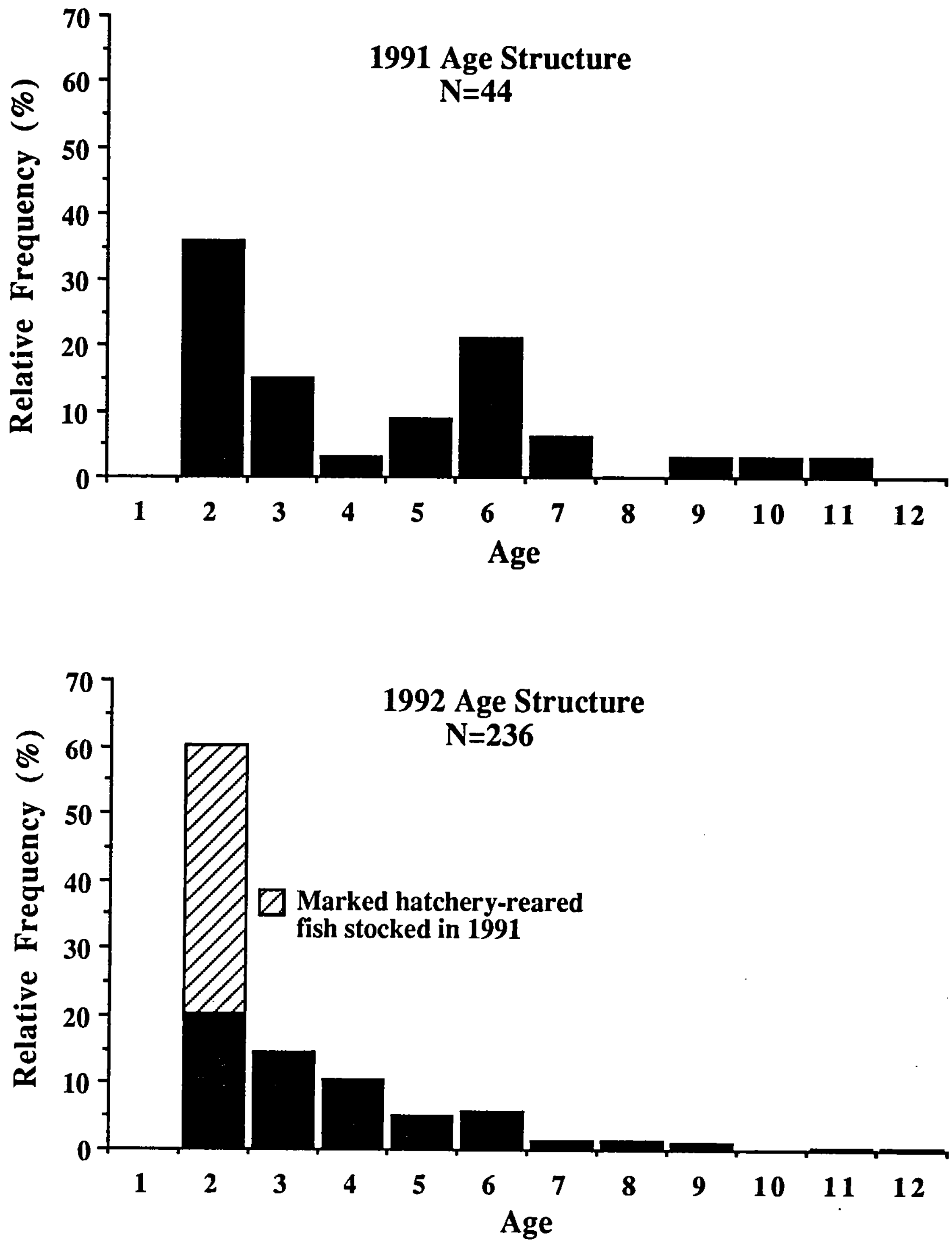
[a] Comparisons were not made between adjusted average catch/net due to violations of statistical assumptions (unequal variance among sites).

Figure 5. Total discharge measured during each sampling period for the Illinois, Kings, and Mulberry rivers, and for the upper, middle, and lower sites on the Buffalo River.



Total Discharge (m3/sec)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Lower Buffalo
Illinois
Mulberry
Kings
Lower Buffalo
Middle Buffalo
Upper Buffalo
June
July

Figure 6. Age structure of adult channel catfish collected from the Buffalo River in 1991 and 1992.


1991 Age Structure
N=44
Relative Frequency (%)
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Age
1992 Age Structure
N=236
Marked hatchery-reared
fish stocked in 1991
Relative Frequency (%)
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
11
12
Age

from previous years, however, no age-1 catfish were collected, and evidence from pectoral spine cross-sections and size at age (see Appendix A) indicated that about 94% of all channel catfish collected from the river during both years had a hatchery origin.

Post-stocking Assessment

Dispersal: The clear water of the Buffalo River provided an unique opportunity for visual observations of the stocked channel catfish following their release in the river on 28 September 1991. For a period of six weeks post-stocking, channel catfish released at each of the three stocking sites exhibited a tight schooling behavior and did not disperse from the original pool in which they were released. No mortality was observed during this period. The stocked catfish could not be visually located following a period of flooding in November, and were not collected from any of the three stocking sites until March 1992 when an angler reported catching 5 marked (right pelvic clip) catfish within 2 km of their original stocking location (Site C). In addition, four marked fish originally released at Site A and three marked fish from Site C were recaptured during April 1992 hoop net-samples at the mouth of Buffalo River (Appendix B); this represents a 163 km downstream dispersal within six months following release of catfish initially stocked at Site A.

A total of 94 marked channel catfish were recaptured in hoop net-samples from various reaches of the Buffalo River during July and August 1992 (Table 5). The majority of these fish (75.5%) were collected in downstream locations from their original release sites, while about 20% were recaptured within 2 km of the original stocking site. Upstream movement was observed only for those fish released at the lower most stocking location (Site C). Channel catfish stocked at the uppermost location exhibited the farthest downstream movement within the Buffalo River, moving an average distance of 103.3 km (Table 5). Further movement downstream into the White River was likely, but was not measured because recapture effort was concentrated exclusively within the Buffalo River. Thus, statistical comparison of average dispersal distance among fish from the

Table 5. Direction and distance (±SD) of post-stocking dispersal of marked channel catfish stocked in the Buffalo River, Arkansas.

	Stocking location				
Variable	A	B	C	Total	Percent
Number recaptured	28	33	33	94	
Movement					
Local[1]	6	0	13	19	20.2%
Upstream	0	0	4	4	4.3%
Downstream	22	33	16	71	75.5%
Mean distance traveled (km)					
Upstream	0	0	26.6		
	—	—	(±9.7)		
Downstream	103.3	66.3	37.0		
	(±61.6)	(±39.9)	(±1.6)		

[1] Within 2 km of original stocking location

three stocking locations was confounded due to unequal variance and could not be made. No significant relationship ($P < 0.05$) existed between fish size and distance moved from original stocking location.

Food Habits: Stomach samples (n=25) collected from hatchery-reared channel catfish four to six weeks post-stocking indicated that if newly stocked fish fed at all, they consumed only a limited variety of small quantities of natural food items (Table 6). In contrast, fish collected 10 to 11 months post-stocking (n=40) consumed a wide variety of natural food items. Forty percent of stomachs collected from catfish four to six weeks post-stocking were empty compared to about 12% of stomachs from catfish collected ten to eleven months post-stocking. Plant material, mostly Spirogyra sp., had the highest rate of occurrence (>50%) of any food item consumed by either group of stocked catfish (Table 6). Comparison of the diets between stocked catfish at 4-6 weeks and 10-11 months post-stocking indicated stocked fish that inhabited the river for a longer period of time were more successful at recognizing and consuming natural food items within the river (Table 7). Analysis of stomach samples (n=12) from non-marked channel catfish (age 2-5; 1 to 3 years post-stocking), collected during the same period (October and November 1991) as the newly stocked fish (4-6 weeks post-stocking), indicated that resident catfish fed on a wide variety of food items; none of their stomachs were empty and more than 20 different food items from all five diet categories were represented in stomach samples. The sample of resident catfish had an average (±SE) of 15.1 (±3.3) food items/stomach with a mean food volume of 32.9 (±11.6) ml/stomach.

Growth: Marked channel catfish collected during July and August had a mean (±SD) total length of 366 (±42.0) mm, an average total weight of 481.2 (±202.0) g, and an average condition factor of 0.93 (±0.11). This represents an average total length increase of about 95 mm, an average weight gain of 310 g (35.6 and 179.7% increase from initial mean length and weight, respectively) and an overall increase in average condition of

Table 6. Frequency of occurrence, percent total volume, and relative importance of food items consumed by stocked channel catfish in the Buffalo River, Arkansas.

	4-6 weeks post-stocking (n=25)			10-11 months post-stocking (n=40)		
Food Item	Occurrence (%)	Volume (%)	Importance Index	Occurrence (%)	Volume (%)	Importance Index[a]
Plant material	56.0	51.2	107.2	65.0	58.8	123.8
Spirogyra	56.0	42.7	98.7	52.5	49.6	102.1
stem & leaf fragments	12.0	8.5	20.5	27.5	9.0	36.5
seeds	0	0	0	5.0	0.3	5.3
Fish	0	0	0	17.5	9.5	27.0
unidentifiable	0	0	0	15.0	9.3	24.3
Ictaluridae	0	0	0	2.5	0.2	2.7
Aquatic inverts/insects	16.0	29.3	45.3	47.5	18.1	65.6
Orconectes	16.0	29.3	45.3	32.5	13.5	46.0
Ephemeroptera	0	0	0	27.5	0.8	28.3
Trichoptera	0	0	0	20.0	1.6	21.6
Plecoptera	0	0	0	15.0	0.5	15.5
Megaloptera	0	0	0	7.5	0.3	7.8
Hemiptera	0	0	0	5.0	1.1	6.1
Odonata	0	0	0	5.0	0.2	5.2
Coleoptera	0	0	0	5.0	0.2	5.2
Diptera	0	0	0	5.0	0.1	5.1
Terrestrial insects	12.0	2.4	14.4	47.5	5.0	52.5
Coleoptera	12.0	2.4	14.4	42.5	4.3	46.8
Orthoptera	0	0	0	12.5	0.7	13.2
Hemiptera	0	0	0	10.0	0.2	10.2
Hymenoptera	0	0	0	2.5	0.1	2.6
Miscellaneous	12.0	17.1	29.1	35.0	8.7	43.7
unident. insect parts	0	0	0	17.5	1.7	19.2
unident. mammal parts	4.0	4.1	8.1	10.0	1.5	11.5
unident. organic matter	12.0	13.0	25.0	7.5	0.5	8.0
rubber fishing jigs	0	0	0	2.5	5.3	7.8

[a] Importance Index = % Occurrence + %Volume

Table 7. Comparison (unpaired t-test) of mean (±SD) number of food categories (plants, fish, aquatic insects/inverts, terrestrial insects), individual food items, and total volume of food items present in the diet of stocked channel catfish at 4-6 weeks and 10-11 weeks post-stocking.

Variable	4 to 6 weeks post-stocking (n=25)	10 to 11 months post-stocking (n=40)	statistic unpaired t-test
Mean number of food categories/fish			
Stomachs	1.0 (±1.2)	2.1 (±1.3)	$P < 0.01$
Intestines	1.2 (±0.8)	2.4 (±1.1)	$P < 0.01$
Mean number of food items/fish stomach	1.3 (±2.0)	3.0 (±2.7)	$P = 0.02$
Mean total volume (ml) of food items/fish stomach	1.4 (±2.3)	4.1 (±4.1)	$P = 0.07$

0.12 from when the fish were initially stocked on 28 September 1991 (~ 300 days post-stocking; Table 8). The weight(W)-length(L) relationship at the time of recapture in July and August 1992 was represented by the equation: $Log_{10}W = -6.1 + 3.4\ Log_{10}L$ (r^2 = .93). This equation was similar to the weight-length relationship observed for the net pen-reared catfish prior to release in the Buffalo River. Stocked channel catfish in the Buffalo River continue to grow rapidly beyond the first year post-stocking, with growth rates of more than 500 g/year through age 4 and over 300 g/year through age 6 (Figure 7).

Proportion of Stocked Fish in the Population: From a total of 236 channel catfish collected from the Buffalo River during July and August 1992, 94 catfish or about 40% of the population sampled, were from the 3,600 marked fish released in upper, middle, and lower sites of the river on 25 September 1991. Analysis of pectoral spine cross-sections and length at age (see Appendix A) revealed that an additional 124 of the 236 (52.5%) adult channel catfish collected were unmarked hatchery-reared fish stocked in previous years or were stocked into tributaries of the Buffalo River in 1991 (Sites 1-4; Figure 2). Thus, of the 236 adult channel catfish collected from the Buffalo River in 1992, more than 92% were from previous AGFC stockings. Analysis of 44 channel catfish spines collected in 1991 indicated about 91% of the population originated from previously AGFC stockings. Only 22 of the 280 (7.9%) channel catfish collected from the Buffalo River during this study originated from natural reproduction and recruitment.

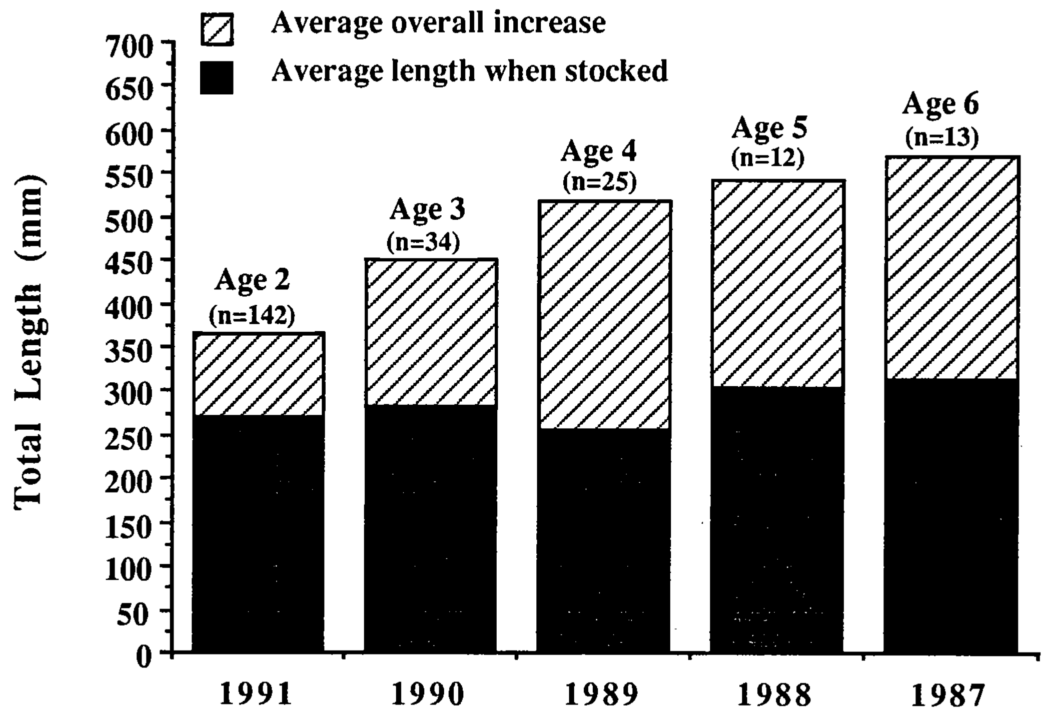
The total population of channel catfish in the Buffalo River was estimated to be about 9,000 fish, with a 95% confidence range of 7,606 to 10,515. This represents about 40 channel catfish per river km, considering only the reaches of the Buffalo River where catfish were collected in 1991 or 1992 (Site A: Figure 2). In addition, it is evident from hoop net CPUE that channel catfish are most abundant in the lower third of the river. Average annual mortality and survival of channel catfish in the Buffalo River (excluding marked hatchery-reared fish stocked in 1991) was 41.8% and 58.2%, respectively. If it is assumed that the marked hatchery-reared fish used in the population estimate were

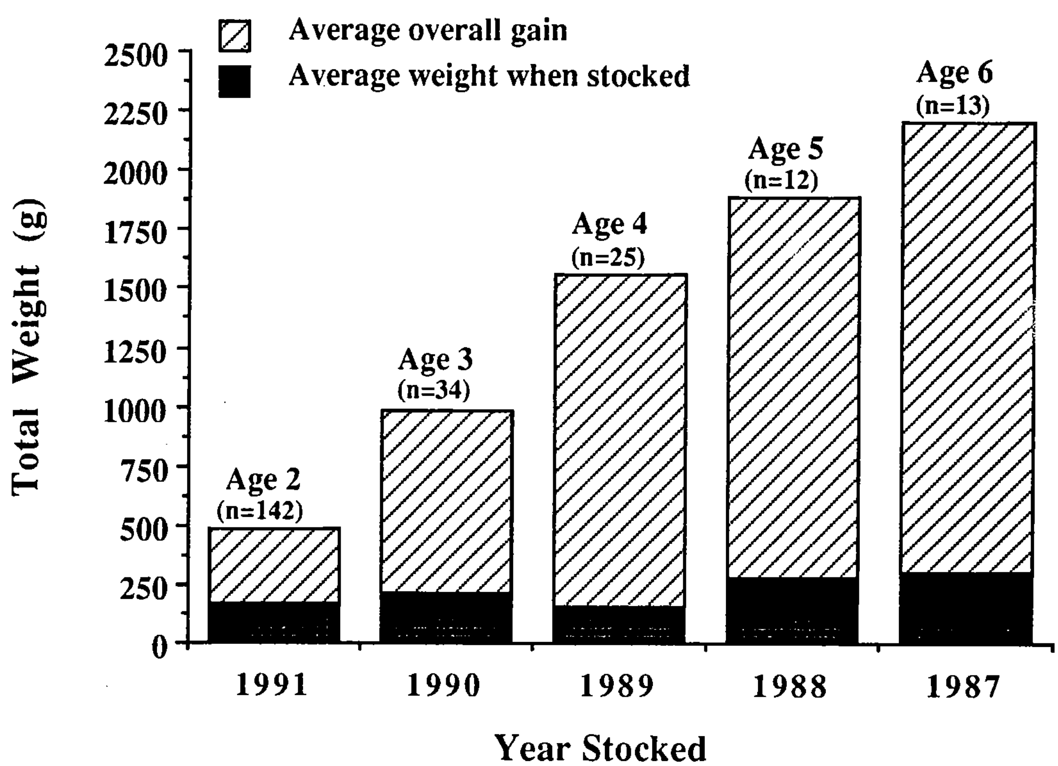
Table 8. Initial (stocked on 25 September 1991) and final (recaptured July-August 1992) length, weight, and condition factor of marked channel catfish stocked in the Buffalo River, Arkansas.

Variable	N	Mean	(±SD)	Range
Final length (mm)	94	366.0	(±42.0)	275.0 - 480.0
Initial length (mm)	110	270.5	(±34.9)	190.5 - 355.0
Mean length increase (mm)		95.5		
Final weight (g)	94	481.2	(±202.0)	170.0 - 1,191.0
Initial weight (g)	110	171.6	(±78.3)	45.0 - 440.0
Mean weight gain (g)		310.6		
Final condition (K)[a]	94	0.93	(±0.11)	0.69 - 1.26
Initial condition (K)	110	0.81	(±0.10)	0.65 - 1.04
Mean condition increase		0.12		

[a] $K = 10^5$(mean weight, g)/(mean total length, mm)^3

Figure 7. Average overall increase in length and weight of channel catfish in the Buffalo River from the time of their original stocking (1987-1991) to recapture in July-August 1992.


Average overall increase
Average length when stocked
Total Length (mm)
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
Age 2
(n=142)
Age 3
(n=34)
Age 4
(n=25)
Age 5
(n=12)
Age 6
(n=13)
1991
1990
1989
1988
1987


Average overall gain
Average weight when stocked
Total Weight (g)
2500
2250
2000
1750
1500
1250
1000
750
500
250
0
Age 2
(n=142)
Age 3
(n=34)
Age 4
(n=25)
Age 5
(n=12)
Age 6
(n=13)
1991
1990
1989
1988
1987
Year Stocked

exposed to similar rates of annual mortality (thus, reducing the original number of marked fish used in the estimate by 42%), then a population estimate of 5,207 fish with a 95% confidence range of 4,412 to 6,100 is obtained. This represents about 23 channel catfish per river km.

DISCUSSION

Reproductive Output and Recruitment

Drift net sampling measured the relative abundance of YOY channel catfish and provided an index of spawning success and/or reproductive output of adult channel catfish for each river. Downstream drift of YOY channel catfish in response to actual adult reproductive activity was demonstrated by Gerhardt and Hubert (1990). Thus, the appearance of YOY channel catfish in drift nets was assumed to represent downstream dispersal from spawning areas, with higher catches representing increased reproductive output.

Location of drift nets within a riffle did not significantly affect catch efficiency; however, nets were not placed in extremely deep or low-velocity areas. Depths of 20 to 55 cm and velocities >20 cm/s seemed to provide the highest overall catches, but no significant relations existed within rivers. In contrast, Armstrong (1984) reported that horizontal (across the channel) drift density of YOY channel catfish appeared to be affected by river discharge levels, and that more YOY catfish drifted near the surface than near the bottom.

The small consistent size of YOY channel catfish collected in drift nets over the 36-day sampling period indicates that catfish greater than 19 mm TL either avoid the nets or are not present in the drift beyond this size. Consistent catches of larger fishes of other species (percids, cyprinids, centrarchids) suggest that larger YOY channel catfish were not present in the drift. Catches of small YOY channel catfish during each sampling period also indicates a protracted spawning period for catfish during June and July in each river. Armstrong (1984) also reported all YOY channel catfish collected in drift nets from the Illinois River were within the size range of 14.0 to 16.0 mm standard length, suggesting that fish size and gear efficiency were consistent between years. In the lower White River, Indiana, Schlueter (1971) collected YOY channel catfish from 25 to 50 mm standard length during August and September by seining shallow water sandbars. Holland-Bartels and Duval (1988) and Pitlo (1991) sampled YOY channel catfish ranging from 15 to 75 mm SL using larval trawls in navigation pools of the upper Mississippi River. The larger size range reported from the above studies suggests that YOY channel catfish were being collected from habitats that are actively utilized for feeding and growth. Absence of YOY channel catfish greater than 19 mm from drift nets may indicate that riffles are not utilized by juvenile catfish larger than this size because larger fish of other species were caught throughout the sampling period.

Drift samples indicate that YOY channel catfish abundance varies significantly among rivers and among different reaches of the Buffalo River. The Illinois River had the highest abundance of YOY channel catfish; however, differences in river size may explain lower abundances from the Kings and Mulberry rivers. Extrapolation of catch data to total discharge in the Illinois River indicated over 22,000 YOY channel catfish drifted past a given point in a single night during peak drift periods. Armstrong and Brown (1983) reported on larval drift for the same sampling site on the Illinois River as Station 1A in the present study. They found similar abundances of YOY channel catfish in drift net samples, with a peak drift occurring on 23 June and 22 July. Their findings and the results of this study indicate that channel catfish reproduction in the Illinois River is probably consistently high during most years. Channel catfish have been historically abundant in the Illinois River and are frequently caught by anglers (Moore and Paden 1950; Geihsler et al. 1975).

The Buffalo River had the lowest abundance of YOY channel catfish of the four rivers sampled. In addition, assessment of the adult population demonstrated an almost complete lack of natural reproduction and recruitment from previous years. It is unclear why YOY channel catfish are less abundant in the Buffalo River because measured physical characteristics do not significantly vary from the other three rivers. Kilambi and Becker (1977) also reported an absence of YOY channel catfish from ichthyo-parasitofauna samples collected at pool and riffle stations in the upper, middle, and lower reaches of the Buffalo River, but nocturnal drift was not measured. The low abundance of YOY channel catfish collected in drift net samples appears to be a direct consequence of the sparse adult catfish population. Cashner and Brown (1977) conducted a longitudinal survey of fishes in the Buffalo River and collected channel catfish only in the lower 8.8 km of the river. The Buffalo River may naturally support only low densities of adult channel catfish, or their numbers may be limited by other factors. Habitat suitability indexes (HSI's) for channel catfish (McMahon and Terrell 1982) indicate that clear water is more suitable for survival and growth; however, observed turbidity levels for the Buffalo River (0.8 ppm) are much lower than the lowest range of the model (100 ppm). In contrast, pond studies have shown that reproduction and survival of young channel catfish are less successful in clear water (Hall and Jenkins 1952; Marzolf 1957) due to greater susceptibility to predation; this relationship may also be true for streams (Pflieger 1975). The extremely clear water of the Buffalo River may result in reduced recruitment due to high predation on YOY channel catfish by the abundant piscivorous fish species present in the river.

One of the most striking differences among the four rivers is the presence of cold tail-waters at the Buffalo River confluence with White River (Figure 1). Water temperature differed by as much as 21.5°C between the White and Buffalo rivers during the 1991 summer sampling period, and YOY channel catfish quickly died from temperature shock when experimentally placed in the colder water taken from the White River. Cold tail-waters, which extend over 160 km below Bull Shoals Dam, has eliminated the historically abundant channel catfish population from this reach of the White River (Brown 1967), and may have eliminated temperature cues needed for upstream migration of adult catfish into the Buffalo River. If cold tail-waters do isolate the Buffalo River from adult channel catfish spawning migrations, this could explain the limited adult population. A number of studies have reported that channel catfish move from larger rivers into smaller tributaries prior to spawning (Humphries 1965; Ranthum 1971; Dames et al. 1989; Smith and Hubert 1989; and others), sometimes migrating as far as 640 km and accounting for a significant proportion (> 75%) of a tributary population (T. D. Pellet and D. Fago, Wisconsin Department of Natural Resources, unpublished data). In the Powder River, Wyoming-Montana, Gerhardt and Hubert (1990) found 36% of radio-tagged channel catfish spawned in tributaries, although tributaries made up less than 1% of the total stream lengths traveled during pre-spawning periods. In Missouri, 50% of transient channel catfish moved from the Missouri River into a tributary stream (Perche Creek) in spring (Dames et al. 1989). Brown (1967) found no indication of large, spring movements of any fish species from the White River into the Buffalo River sixteen years after completion of Bull Shoals Dam. In addition, spring hoop-net sampling at the mouth of the Kings, Mulberry, and Buffalo rivers in 1992 revealed significantly ($P < 0.05$) fewer channel catfish migrated into the Buffalo River compared to the other two rivers (see Appendix B).

Longitudinal abundance of YOY channel catfish within the Buffalo River was significantly higher in the lowest reach. The upper reach of the Buffalo River does not appear suitable for channel catfish reproduction, as no YOY catfish were collected above Station 5A (Figure 1). Absence of YOY channel catfish was also observed in the upper Kings River station (3B). The absence of YOY channel catfish in the upper stations of both the Kings and Buffalo rivers may due to a lack of suitable habitat for adult fish during spawning or lack of suitable spawning conditions in these reaches; both become intermittent during late summer. Adult channel catfish may avoid first and second order streams because of intermittent discharge patterns typical of headwater reaches in Ozark streams. In the upper Mississippi River, Helms (1975) reported similar catches of YOY channel catfish among navigation pools and concluded that factors controlling spawning success were similar throughout the entire river. In contrast, trawl data from navigation pools 9, 11, 16, and 18 of the upper Mississippi River from 1985 to 1991 (Pitlo 1991) indicated that levels of reproductive output may be independent among individual pools, with a trend for higher abundance of YOY channel catfish in downstream pools. Holland-Bartels and Duval (1988) found no consistent variation in abundance of YOY channel catfish in the main channel of a navigation pool of the upper Mississippi River.

Longitudinal differences in YOY channel catfish abundance in the Buffalo River coincided with relative abundance of adult channel catfish. Eighty-four percent of YOY channel catfish collected from the Buffalo River were taken at the lowest station (4A), while more than 86% of adult channel catfish were collected in proximity to the lower river site despite lower sampling effort for adults in this reach. In addition, 75% of the marked channel catfish stocked in 1991 were recaptured downstream of their original release locations, with most of these fish recaptured in the lower third of the Buffalo River. This extensive downstream movement, higher density of adult fish, and higher abundance of YOY catfish illustrate the significant preference and greater abundance of channel catfish in the lowest reaches of the Buffalo River.

Natural resource agencies charged with maintaining catchable populations of channel catfish in streams may be able to use information on abundance of YOY channel catfish drift to assess supplemental stocking needs. As Helms (1975) suggested for trawling in large rivers, larval drift nets may be a useful technique for predicting future year-class strength of channel catfish for smaller river systems if relationships are confirmed between YOY abundance and age 1 abundance the following year. In navigation pools of the upper Mississippi River, Pitlo (1991) noted high trawl catches of YOY channel catfish showed up as strong age-1 year-classes the following year, and years of low trawl catches resulted in weaker age-1 year-classes the following year. This type of information is important for evaluating recruitment fluctuations, future population abundance, and early detection of supplemental stocking needs.

Based on results of this portion of the study, drift nets are useful for detecting differences in reproductive output of channel catfish among rivers, and may reflect relative abundance of the adult population. Drift net results indicate that the Kings, Mulberry, and Illinois rivers have abundant channel catfish reproduction. Annual fall stocking of additional channel catfish in these rivers probably contribute little to the existing populations. In contrast, evidence from this study strongly suggests the Buffalo River does not support a self-sustaining channel catfish population, as few YOY catfish were found, and age structure assessment indicated only a fraction of naturally spawned catfish from previous years have been recruited into the adult population. To adequately evaluate the use of drift nets for early detection of supplemental stocking needs, further investigation is needed to provide a longer-term data base on trends of YOY channel catfish abundance in small riverine systems. Additional information is also needed to confirm relations between abundance of YOY channel catfish and abundance of age-1 fish the following year.

Post-Stocking Assessment

Dispersal: Following stocking in the Buffalo River, channel catfish formed one or more tight aggregations, exhibiting a schooling behavior, and remained within the original pool in which they were released for six weeks post-stocking. Brown et al. (1970) and Randolph and Clemens (1976) also noted schooling tendencies of hatchery-reared channel catfish in hatchery ponds and following release in the wild. The hatchery-reared catfish used in this study were reared in clear water net pens prior to stocking and likely developed visual aggregation behavior during feeding. The clear water of the Buffalo River allowed the stocked fish to remain in visual contact until a period of high water occured in November 1991. After the water cleared, stocked catfish were not visually located again. This period of flooding, which coincided with high turbidity levels and low visibility, is thought to have resulted in the break-up of the tight aggregations of catfish and initiated downstream dispersal from the original stocking locations. Seaman (1948) also noted that periods of high water may have caused downstream migration of channel catfish stocked in the Ohio River.

Previous tagging studies in riverine systems have shown that wild channel catfish exhibit extensive directional and seasonal movements (Muncy 1958; McCammon 1956; Hubley 1963; Humphries 1965; Welker 1967; Hale et al. 1986; Dames et al. 1989). However, Seaman (1948) provided one of the only published accounts of post-stocking dispersal of hatchery-reared channel catfish released in a riverine system. He reported that angler returns (n=99), from 1,800 catchable-size (305 mm) channel catfish tagged and stocked during May in two Ohio River tributaries, indicated substantial movement. Only two fish were recaptured above the original stocking location within the tributaries, but 10% were recaptured in upstream locations in the Ohio River and 90% moved out of the tributary and downstream in the Ohio River, one as far as 382 km through several locks and dams (Seaman 1948). These results are similar to those observed for stocked catfish released in the Buffalo River, where 75% of all fish recaptured had moved downstream, with additional downstream movements into the White River likely, but not sampled. Bryson et al. (1975) also reported on returns from stocked catfish in a lotic system, but no up- or downstream movement patterns were determined because they did not obtain enough recaptures, and their creel survey was conducted almost exclusively at the initial stocking sites. Wickliff (1933) reported that channel catfish transplanted from Lake Erie into several Ohio streams moved downstream, with additional down-stream movements obstructed by one or more dams. Hubley (1963) also reported on channel catfish (n=2,300) that were tagged and transplanted 176 km upstream from their capture location in the upper Mississippi River; movements determined from tag returns (n=167) indicated 65% of the fish moved upstream, 25% moved downstream, and 10% remained within 3.2 km of the release site. Based on tagging studies of wild channel catfish in riverine systems, the initial up- or downstream movement of stocked catfish may be more related to season of stocking than any other factor, with up- or downstream movement more likely for catfish stocked in the spring or fall, respectively. Shetter (1947), Needham (1959), and Cresswell (1981) provide reviews of the numerous investigations conducted on post-stocking movements of trout in flowing waters; in general, they reported greater dispersal of all trout species if fish overwinter prior to capture or if fish have been stocked in small upstream reaches.

Food Habits: There have been numerous studies on the food habits and diets of wild channel catfish from various rivers in the United States (Menzel 1945; Baily and Harrison 1948; Stauffer et al. 1976), however, no information is available on the food habits of channel catfish inhabiting clear-water streams characteristic of the Ozark region. In addition, no published information exists on the food habits of hatchery-reared channel catfish released into flowing waters. Information on food habits of stocked catfish is critical for evaluation of the current stocking program in the Buffalo River, because the events associated with food and feeding can dominate ecological relationships within a fish community (Wallace 1981). For example, severe inter- or intraspecific competition, population limitations, and poor growth rates may result from significant diet overlap of key food resources. Diet overlap among fish species has been calculated in several studies to detect these competitive relationships (Wallace 1981). Thus, food competition may limit production and reduce the abundance of desirable fish species within a community.

Net pen-reared channel catfish were able to feed following initial release in the Buffalo River, and were easily caught by pole and line sampling. Algae (Spirogyra) and other plant material was the most common food category present in the diets of catfish collected at 4 to 6 weeks and 10 to 11 months post-stocking. It is unclear whether the fish were feeding on the algae directly or on organisms associated with the algae, with no direct preference for the algae itself. Other authors have reported algae and aquatic plants to be significant items in the diet of channel catfish (McCormick 1940; Dill 1944; Menzel

1945), but they gave no indication of its utilization. In the Buffalo River, algae found in the intestines of newly stocked fish with relatively empty stomachs showed signs of some utilization because cell walls were broken down. In contrast, channel catfish with large amounts of algae in the intestines showed no sign of utilization.

The lack of feeding and relatively few types of food items consumed by hatchery-reared channel catfish at 4-6 weeks post-stocking suggests newly stocked fish were unable to recognize natural food items within the Buffalo River, or were unsuccessful in feeding within a large aggregation. Stocked channel catfish inhabiting the river for a longer period of time (10-11 months) were more than twice as successful in feeding and consumed a wider variety of natural food items than recently stocked fish. Similarly, Ersbak and Haase (1983) found that wild brown trout (Salmo trutta) were twice as successful in feeding than stream-stocked brook trout (Salvelinus fontinalis). Hatchery-reared channel catfish adapted to a commercial pelleted diet may require a learning period to identify natural food items in the wild. Since catfish are stocked in Buffalo River in late September, this period of nutritional deprivation may lead to higher overwinter mortality if fish do not begin feeding prior to depletion of pre-stocking fat reserves. Nutritional deprivation following stocking has been considered a possible mechanism leading to mortality in stream-stocked trout (Reimers 1963, Ersbak and Haase 1983); in both studies, condition of hatchery trout declined steadily following release into the wild, while resident trout maintained a stable condition throughout the study period. This led to a higher mortality of stocked trout during critical late winter periods. Although average condition of stocked catfish in the present study had increased from the time of stocking until collection in 1992, the smaller, weaker fish with poor initial condition may simply not have survived.

The relative numbers of food items consumed by stocked channel catfish (10-11 months post-stocking) in the Buffalo River appears to coincide with relative availability of natural food items within the river, although direct measurements of availability were not made. For example, mayflies (Ephemeroptera) were the dominant aquatic insect found in the diet of channel catfish in the Buffalo River, and are one of the most abundant aquatic insect orders in the river (Mike Mathis, University of Arkansas, Personal Communication). Similarly, Mitzner (1990) reported on the food habits of maintenance-stocked channel catfish (one and two years post-stocking) in several Iowa lakes and found that dominant food items present in the diet varied among lakes, but appeared to be related to relative availability of food items within each lake.

Growth: First year growth increases (95 mm and 310 g) of stocked channel catfish in the Buffalo River are comparable to growth rates reported for catfish stocked in lakes. Mitzner (1990) reported that channel catfish stocked in Red Haw Lake, Iowa, had an average increase in length of 147 mm during their first year in the lake. However, those fish were stocked at a smaller initial size (127-152 mm) than catfish stocked in the Buffalo River. In Pony Express Lake, Missouri, Eder and McDannold (1987) showed that stocked channel catfish had an average length increase of 162 mm following two growing seasons. Stocked channel catfish in the Buffalo River continue to grow rapidly through age 6. These rapid growth rates likely reflect low levels of inter- and intraspecific competition, and an abundant food supply in the Buffalo River. It has also been shown that channel catfish inhabiting clear water exhibit more rapid growth rates because of higher visibility of potential food items (Hall and Jenkins 1952; Carlander 1969; McMahon and Terrell 1982).

The method used to calculate overall growth rates of stocked channel catfish in the Buffalo River (mean size) does not take into consideration the possibility that smaller hatchery fish may have had higher mortality rates than larger hatchery fish following release in the river. Previous studies have clearly demonstrated a relationship between catfish size and post-stocking mortality (Mestl 1983; Storck and Newman 1988). Thus, if smaller fish stocked in the Buffalo River had higher mortality than large fish they would not have been represented as well in recapture averages, resulting in an artificially higher average growth rate.

Contribution of the stocked fish: A number of investigators have reported on angler return rates for catchable-size channel catfish stocked in lakes, with variable results. For example, Mitzner (1990) reported that exploitation rate of maintenance-stocked channel catfish in four Iowa lakes ranged from 19 to 85%. Armstrong (1986) reported that the number of channel catfish harvested from nine state-owned lakes in Arkansas ranged from 7 to 108% of the total number stocked. In Pony Express Lake, Missouri, Eder and McDannold (1987) found that, although first year exploitation was low (9-11%), 64% of the 131,519 channel catfish stocked over a 21-year period were eventually harvested by anglers. In contrast, Lewis et al. (1963) reported a 1.2% return of catchable size channel catfish stocked in a 12 ha Illinois lake with an established fish population. However, stocked catfish made up a significant portion (36%) of all channel catfish caught from the lake that year.

Although information exists on angler return rates and survival of channel catfish stocked in small impoundments, little information exists on the fate of hatchery-reared catfish released into flowing waters. This is partially due to the complexity of riverine systems and because many rivers naturally support abundant channel catfish populations and therefore are not stocked. Voluntary tag returns of hatchery-reared channel catfish tagged and released in two Ohio River tributaries resulted in a 5.5% angler harvest rate of the stocked fish (Seaman 1948). Bryson et al. (1975) found less than 1.7% of catfish stocked at three locations on the New River, Virginia were recovered in the creel. However, in this study the creel survey and other sampling efforts were concentrated at the three stocking sites. Studies on returns of hatchery-reared fish other than channel catfish released into flowing waters have also yielded variable results. For example, Funk and Fleener (1974) found less than a 3% return of hatchery-reared smallmouth bass (Micropterus dolomieu) stocked in Big Piney River, Missouri.

Although this study does not provide information on angler return or harvest of the stocked fish released in the Buffalo River, the significant proportion (>94%) of hatchery-reared channel catfish within the population clearly illustrates the important contribution of the stocked fish to the overall population of adult fish in the river. The significant proportion of hatchery-reared channel catfish within the Buffalo River population is much higher than any other known riverine population. From total catch data of stocked catfish reported for the New River, Virginia (Bryson et al. 1975) it was calculated that stocked channel catfish accounted for only 3.5% of the catfish harvested from that reach of river during the sampling period. The authors suggested the stocked catfish may not have survived because the fish were from a commercial strain not adapted to a lotic environment. Results of this study and the findings of Seaman (1948) suggest that most of the stocked fish may have dispersed from the original release sites, resulting in an unreliable conclusion for channel catfish stocked in the New River. In addition, Eder and McDannold (1987) have shown that first year exploitation of stocked channel catfish is low compared to overall harvest in subsequent years. Although a significant portion of the existing channel catfish population in the Buffalo River originates from stocked fish, there is no evidence of heavy angler pressure or significant exploitation of catfish, in spite of increasing visitor use. The National Park Service estimates more than 60,000 anglers fish the Buffalo River each year, but only one angler-harvested catfish was reported from a day-time creel survey conducted on the river in 1991 (Horton and Johnson 1991).

Mortality and Survival: Pond and lake studies have demonstrated higher survival rates and cost-efficient angler returns are obtained from stocking larger sized catfish (Mestl 1983; Spinelli et al. 1985; Storck and Newman 1988), but information is not available on survival of catchable sized fish stocked in rivers. Most studies of catchable size channel catfish stocked into ponds and lakes have generally shown high survival rates (e.g., Adair 1981; Eder and McDannold 1987). In contrast, Storck and

Newman (1988) reported that catfish (mean total length, 202 mm) stocked in a 6.1 ha impoundment suffered 55 and 73% natural mortality after one and two growing seasons, respectively. Estimates from this study suggest an average annual mortality rate of about 42% for catfish stocked in the Buffalo River. Considering the extensive downstream movement of stocked channel catfish to the lower reaches of the Buffalo River, this mortality estimate probably includes a number of fish that migrated completely out of the river and into the White River beyond my capture efforts. Therefore, the resulting annual mortality estimate for stocked catfish in the Buffalo River is a combined estimate of mortality plus emmigration of catfish out of the river. Based on creel survey results (Horton and Johnson 1991), angler harvest does not appear to contribute significantly to total mortality of stocked catfish in the Buffalo River.

Population Estimate: The population estimate for channel catfish in the Buffalo River relied on the marked hatchery-reared fish as an appropriate marker in place of the standard method of marking wild fish obtained directly from the population. This technique has been utilized in other investigations and has been determined to be reliable if the underlying assumptions of mark-recapture have been met. For example, in the Columbia River, Peven and Hays (1989) used proportions of hatchery-reared and naturally produced steelhead (Oncorhynchus mykiss) to estimate the total run size of smolts migrating past Rock Island Dam, and determined hatchery steelhead made up over 72% of the run. Hepworth et al. (1991) used supplemental stocking (hatchery fish in place of marked fish) for estimating population size of rainbow trout (O. mykiss) in a Utah reservoir. The authors tested assumptions of the mark-recapture estimate when using stocked trout as the marked fish and concluded that hatchery-reared fish could be used successfully to obtain reliable population estimates and to evaluate the success of stocking programs if each assumption of the mark-recapture method was met. Use of marked hatchery-fish for the population estimate of channel catfish in the Buffalo River appears to adequately meet the assumptions of a Peterson estimate (Ricker 1975). An exception may be the assumption that no mortality or emmigration of the stocked fish may occur between the time of marking and recapture. In the present study, this factor was accounted for by adjusting the initial number of marked fish with the estimated annual mortality rate (42%). Thus, the 95% confidence interval of 4,412 to 6,100 channel catfish is believed to be a fairly realistic and reliable estimate of the channel catfish population in the Buffalo River.

Impacts of Stocking: Marnell (1986) outlined several potential impacts of hatchery stocks upon wild fish populations and the natural fish community. These potential impacts include:

1. Introduction of pathogens and parasites
2. Hybridization or genetic alterations
3. Predation on native species
4. Competition for food and habitat
5. Altered growth and survival
6. Displacement and extinction of native species

Most investigations on the effects of hatchery-reared fish on native stocks have been conducted for salmonid species. Actual elimination of wild populations in response to stocking hatchery-reared game fishes has occurred in only a few instances (Marnell 1986). In contrast, Hilborn (1992) suggests that large-scale hatchery programs for salmonids in the Pacific Northwest have not provided anticipated benefits, but rather current stocking programs may pose the greatest single threat to long-term maintenance of existing salmonid stocks.

Although the effects of pathogen and parasite introduction are unknown, no apparent effects of channel catfish stocking on other fishes of the Buffalo River were detected. Channel catfish are native to the Buffalo River drainage; fossil remains found in the drainage date back to a period 1,100-1,800 years before present (Guendling et al. 1990). Information from food habit analysis and abundance estimates for stocked channel catfish in the Buffalo River suggest that few negative impacts to the aquatic community result from current stocking rates. The wide variety of food items consumed, rapid growth rates, rapid dispersal, and relatively sparse population of channel catfish in the Buffalo River strongly suggest a low level of direct competition with other species.

Previous studies on the effects of channel catfish stocking on the resident biota have produced inconsistent findings. Some studies have documented adverse effects on other species caused by channel catfish stocking. Crance and McBay (1966) noted average weight of "bream" (Lepomis spp.) was 30% less in Alabama ponds stocked with 370 channel catfish/ha. Mitzner and Middendorf (1975) found that consecutive annual stockings of 153, 163, and 415 channel catfish/ha in an Iowa pond resulted in a decline in the catch and growth of largemouth bass, bluegills, (Lepomis machrochirus) and crappies (Pomoxis spp.). Competition for food between channel catfish and bluegill was demonstrated at Lake Ellis, Iowa (Mitzner 1990), due, in part, to the extremely low biomass (10 kg/ha) of benthic invertebrates found in that lake. In contrast, Eder and McDannold (1987) reported that no negative effects on other species could be related to over 25 years of channel catfish stocking in a Missouri reservoir, while Lewis et al. (1963) found an unexpected increase in the catch of native fish species the year hatchery stockings of channel catfish were made.

Results from this portion of the study provide baseline information on the fate of hatchery-reared channel catfish stocked into a riverine system. Although channel catfish is a well studied and important sport and commercial species, and catfish stocking programs currently exist in 35 states (Smith and Reeves 1986), review of the literature indicates that little or no information is available on angler harvest, survival, dispersal, food habits, or growth of hatchery-reared catfish released into flowing waters. Considering the wide-spread popularity of channel catfish stocking programs in the United States, it is unclear why so many information gaps currently exist. This may be partially due to the complexity of riverine systems and that only a few states with catfish stocking programs actually stock catfish in rivers because they naturally support self-sustaining, wild catfish populations.

Post-stocking evaluation of catchable size channel catfish released in the Buffalo River has revealed that more than 94% of the existing adult population originated from hatchery stocks, and that continued stocking may be required to maintain the species in this river. Stocked catfish in the Buffalo River exhibit extensive downstream movements, feed on a wide variety of natural food items, have rapid growth rates, and do not appear to have any noticeable competitive impacts on other fishes of the river. Future research should focus on further identifying reasons for the sparse number of naturally recruited catfish in the population, and to more thoroughly assess potential impacts of continued supplemental stocking. If the goal of future stocking in the river is to re-establish a self-sustaining population, rather than simply maintaining a catchable population, then stocking efforts should focus on planting strains of adult fish that are more genetically adapted to clear-water Ozark streams. Although this could be accomplished by obtaining catfish stocks from similar type clear-water streams with self-sustaining populations, long-term success may not be achieved because of irreversible changes to the historic Buffalo River drainage (such as cold White River tail-waters) that may have permanently eliminated or isolated critical seasonal habitats.

SUMMARY

1. Larval drift nets were useful in measuring reproductive output of channel catfish in small riverine systems. Reproductive output of channel catfish in the Buffalo River was significantly lower than similar type Ozark rivers in northwest Arkansas.

2. Age structure assessment of channel catfish in the Buffalo River reflected the lack of reproductive output detected from drift net samples and indicated a lack of natural reproduction and recruitment from previous years. No age 1 channel catfish were collected in 1991 or 1992, and only a fraction of all catfish collected in the river (< 8%) originated from natural reproduction and recruited into the population.

3. Hatchery-reared channel catfish in the Buffalo River could be identified using pectoral spine cross-sections (Appendix A) by the presence of wide increments of growth between the first and second annuli (corresponding to rapid growth in the hatchery) followed by narrower increments in all subsequent annuli (corresponding to natural growth in the river).

4. Elimination of historic inputs from migratory channel catfish stocks into the Buffalo River due to the presence of cold White River tail-waters (Appendix B) and low turbidity levels are suggested as the two main factors attributed to lower reproductive output and recruitment in the Buffalo River, relative to the Kings, Mulberry, and Illinois rivers.

5. Evaluation of reproductive output and recruitment success were useful assessment techniques for determining stocking needs of channel catfish. Stocking appears important for maintaining current population levels in the Buffalo River, while stocking does not appear necessary in the Illinois, Kings, and Mulberry rivers.

6. Catchable size channel catfish fall-stocked in the Buffalo River remained in the original pool in which they were stocked for a period of six weeks, but eventually distributed throughout the river, exhibiting extensive downstream movement following a period of flooding; 75% of all recaptures were collected in downstream locations.

7. Stocked channel catfish consumed few natural food items during the first four to six weeks following stocking, but were found to consume a wide variety of food items when sampled at 10-11 months post-stocking. This suggests that newly stocked, net pen-reared, catfish did not recognize natural food items when initially released in the river, and that the stocked catfish went through a period of "learning" following release in the Buffalo River.

8. Stocked channel catfish in the Buffalo River exhibited rapid growth rates through age 6.

9. The population of channel catfish in the Buffalo River was estimated to be about 5,200 fish, with a 95% confidence range of 4,412 to 6,100 fish.

10. Average annual mortality (plus emmigration into the White River) of catchable size channel catfish stocked in the Buffalo River was estimated to be 42%.

11. Based on the diverse food habits, low population density, and rapid growth rates of stocked channel catfish in the Buffalo River, it does not appear that catfish stocked at the current rates have any noticeable negative impacts on other fishes of the river.

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APPENDIX A

IDENTIFICATION OF HATCHERY-REARED CHANNEL CATFISH IN THE BUFFALO RIVER USING PECTORAL SPINE CROSS-SECTIONS

ABSTRACT

Cross-sections of pectoral spines were used to identify hatchery-reared channel catfish (Ictalurus punctatus) so that relative contribution of supplementally stocked catfish could be assessed in the Buffalo River, Arkansas. Previous methods to identify hatchery-reared fish have employed a variety of marking techniques, however, no information is available on the use of bony structures to identify hatchery-reared channel catfish within wild populations. Analysis of pectoral spine cross-sections from channel catfish collected in the Buffalo River indicated hatchery-reared catfish could be identified by the presence of wide growth increments between the first and second annuli (corresponding to hatchery growth) followed by narrow annual increments beyond age 2 (corresponding to post-hatchery growth). This method was verified by analysis of pectoral spines obtained from marked channel catfish stocked in 1990 and 1991. Observed length at age of Buffalo River channel catfish in comparison to catfish from other waters also indicated these were previously stocked fish. Previously stocked fish accounted for greater than 93% of the catfish sampled in the Buffalo River. The lack of naturally recruited channel catfish in the river was supported by an absence of age-1 catfish in the population. This method should be applicable in other regions if catchable size channel catfish are being used in stocking programs.

INTRODUCTION

To evaluate the success of fish stocking programs, fishery managers must be able to assess survival of the stocked fish and determine relative contribution of the hatchery-reared fish to the existing population. If supplemental stockings of hatchery-reared fish are released into waters supporting a wild population, a technique to identify the hatchery-reared fish is required to evaluate their contribution to the existing population. In the past, a variety of marking techniques have been used to identify hatchery-reared fish from wild stocks. Of these, scale size, shape, and age marks (radii and annuli) on scales are the most frequently used morphological characteristics (Wydoski and Emery 1983). For example, Chapman (1958) noted differences between scale patterns of wild and hatchery-reared steelhead (Oncorhynchus mykiss) in Oregon. Seelbach and Whelan (1988) quantified these scale pattern differences and used them to identify and assess the contribution of hatchery stocks to the steelhead fishery in the Great Lakes region. In Arkansas, Buchanan and Strawn (1969) used scale size at formation of the first annulus to distinguish hatchery-reared smallmouth bass (Micropterus dolomieu) from native smallmouth in three headwater streams. Scale marks induced through starvation (Major 1962), deposition of tetracycline drugs in scales and bony structures (Weber and Ridgeway 1962), as well as numerous other techniques have also been used to identify hatchery-reared fish.

The same factors that result in abnormal scale growth also affect bony structures of scale-less fish because of relationships between fish size and bone radius (Appelget and Smith 1951; Sneed 1951). However, no information is available on the use of differential growth patterns of bony structures to identify hatchery-reared channel catfish (Ictalurus punctatus) within a wild population. Various techniques used for marking large numbers of channel catfish have included dyes, fluorescent pigments, and hot and cold branding (Hill et al. 1970) as well as floy-tags, fin-clips (Hale et al. 1983) and tetracycline drugs. Age-length relationships have been evaluated as a potential method to differentiate geographically isolated stocks of adult channel catfish (Ashley et al. 1981). However, the authors reported this method was valid only when strains of fish being used came from widely separated geographic areas. The main advantage of using morphological characteristics such as differential spine growth is that hatchery stocks can be identified in systems with minimal planning or additional tagging effort, and fish from any previous stockings can be differentiated from wild fish. Thus, the occurrence and contribution of unmarked hatchery fish, which were previously stocked into waters supporting a wild population, can be evaluated.

The purpose of this paper was to compare the differences in annuli formation on pectoral spines between wild and hatchery-reared channel catfish and to use this technique to comparing TL at age of Buffalo River channel catfish to TL at age reported for wild catfish stocks from other rivers. Rapid growth prior to formation of the second annuli reflects the continuous feeding and increased growth experienced by hatchery-reared fish. Slower growth following formation of the second annuli corresponds to post-hatchery growth in the river. The small number of slow growing channel catfish collected (Figure 1-C) were considered to be either wild fish reproduced in the Buffalo River, or wild migrants from the White River. It is also possible that slower growing fish from the net pens lay down narrow growth rings, but the majority of these fish exhibit rapid growth rates on commercial diets, and none of the spines obtained from marked catfish (n=101) had poor growth prior to formation of the first or second annuli.

Hatchery-reared channel catfish appeared to account for a significant proportion (> 93%) of the adult catfish population in the Buffalo River. Assuming equal vulnerability of stocked and wild channel catfish to the sampling gear, the ratio of hatchery-reared to wild fish is significant and suggests a sparse wild population within the Buffalo River. The lack of naturally recruited channel catfish in the Buffalo River is clearly supported by an absence of age-1 fish in 1991 and 1992 samples. In the Columbia River, Peven and Hays (1989) used proportions of hatchery-reared and naturally produced steelhead to estimate the total run size of smolts migrating past Rock Island Dam, of which hatchery steelhead made up over 72% of the run. Hepworth et al. (1991) also used supplemental stocking (using hatchery fish as the sample of marked fish) for estimating population size of rainbow trout (Oncorhynchus mykiss) in a Utah Reservoir. They tested assumptions of the mark-recapture estimates when using stocked trout as the marked fish and concluded that hatchery-reared fish could be used successfully to obtain reliable population estimates and to evaluate the success of stocking programs if each assumption of the mark and recapture method is met.

Cross-sections of pectoral spines were useful to determine the presence of previously unmarked, hatchery-reared, channel catfish in the Buffalo River, and for assessing their contribution to the existing population. Using characteristics of annuli formation and comparing TL at age to that reported for other waters, hatchery-reared channel catfish could be readily identified even seven years after stocking. Some of the most important characteristics of good marks are permanence, ease of application and detection, and no detrimental effects on the fish (Arnold 1966). The method described for identification of hatchery-reared channel catfish fits these criteria, with the additional advantage of no previous planning or effort required to mark the fish. This method should also be applicable in other regions if catchable size channel catfish are used in the stocking program. Similarly, Seelbach and Whelan (1988) noted that scale characteristics used to identify wild and hatchery steelhead could be applied in other regions and, possibly, to other species if reared a full year in a hatchery. Additional investigation of this technique from other waters is needed to fully evaluate the usefulness of pectoral spine cross-sections to distinguish stocked channel catfish from wild catfish, and for evaluating the stocking success and contribution of hatchery-reared catfish.

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Figure 1. Examples of pectoral spine cross-sections of channel catfish collected from the Buffalo River showing the rapid increase in growth prior to formation of the first and second annuli (arrows) observed in hatchery origin fish. The top spine (A) is a known, age-2, hatchery origin catfish; the middle spine (B) was determined to be from a previously stocked, age-5, catfish; and the bottom spine (C) was determined to be from a non-stocked, age-10, catfish.

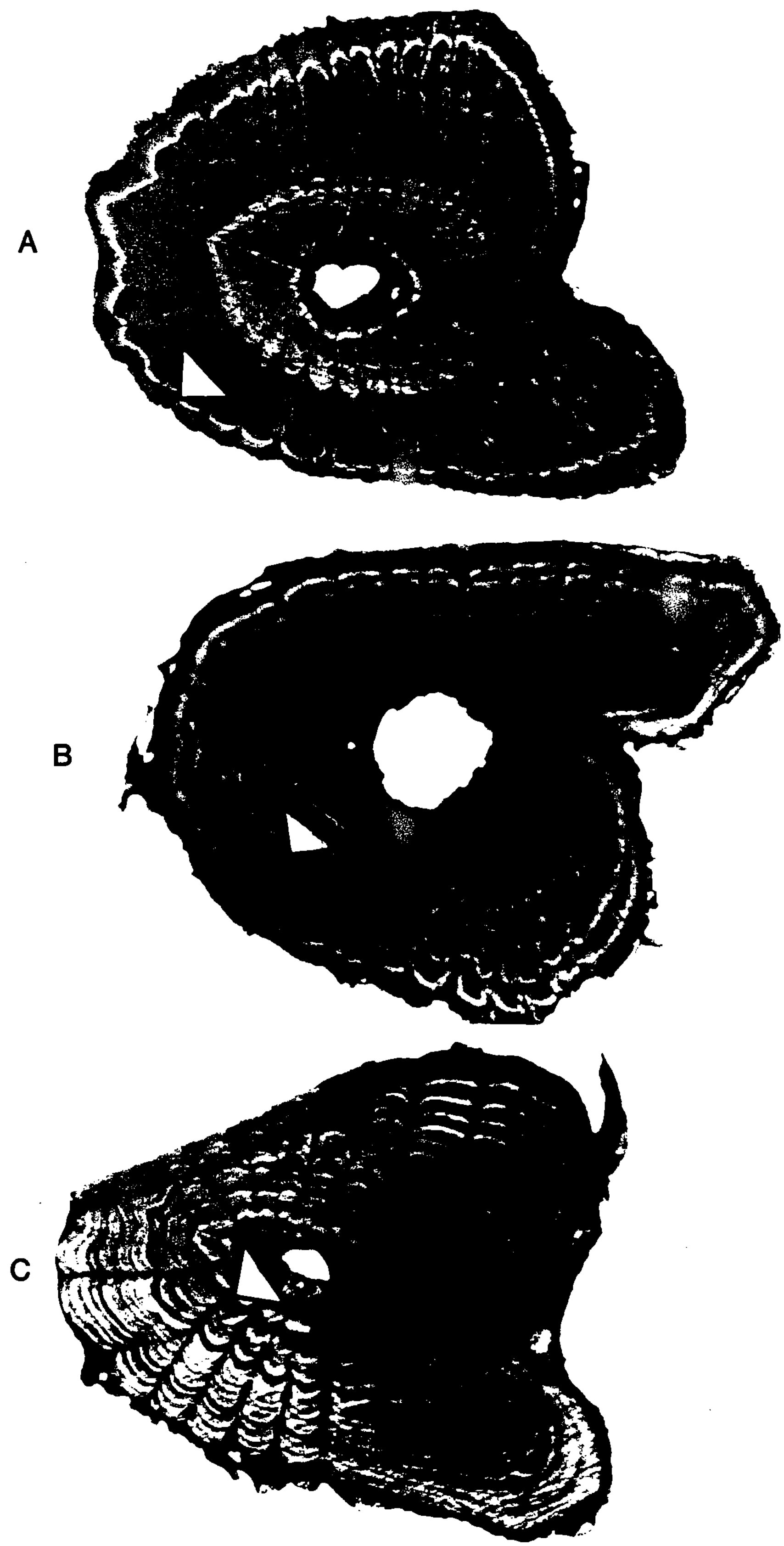
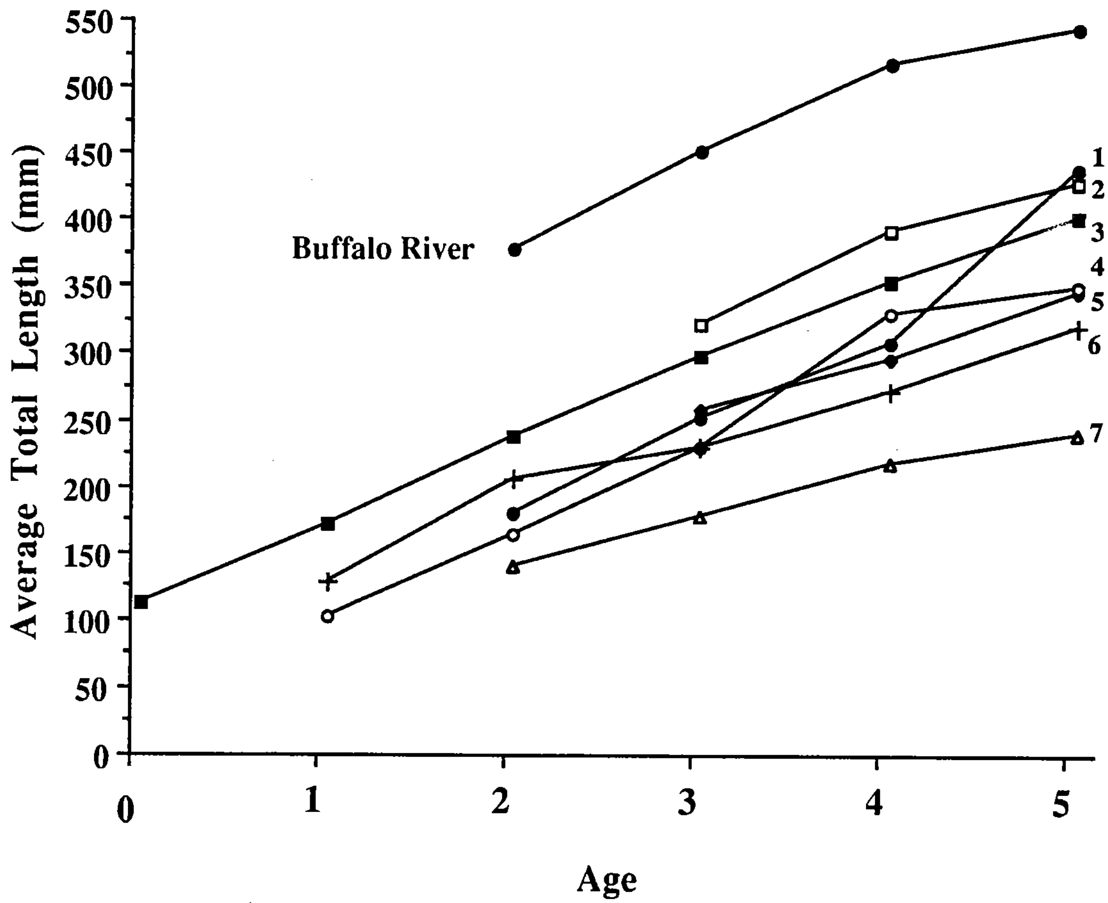
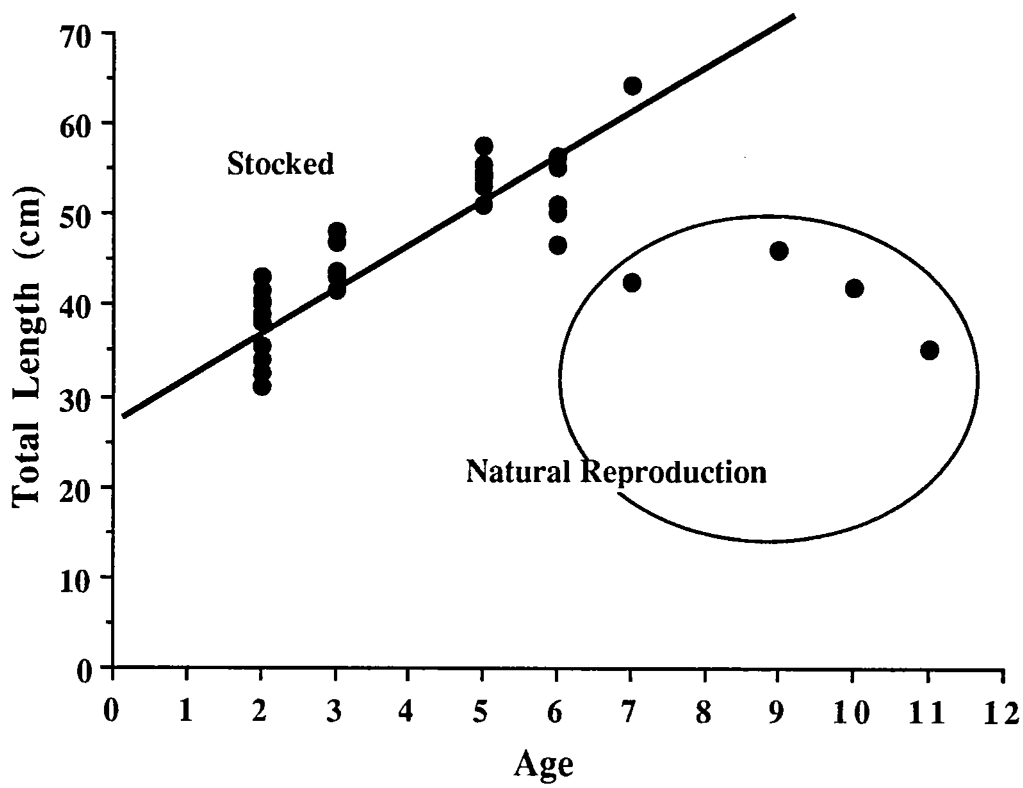

A
B
C

Figure 2. Comparison of mean length at age for hatchery origin channel catfish collected in the Buffalo River to mean lengths reported for wild stocks from other waters: **1**-Little River, OK (Finnell et al. 1956); **2**-Illinois River, OK & AR (Jenkins et al. 1952) **3**-Cedar River, IA (Schoumacher and Ackerman 1965); **4**-Mississippi River, IA (Schoumacher and Ackerman 1965); **5**-Missouri River, NE (Hesse et al. 1978); **6**-Arkansas River, AR (Freeze and Tatum 1977); **7**-Des Moines River, IA (Harrison 1957).



1=Cedar River, Iowa (Schoumacher and Ackerman 1965)
2=Mississippi River, Iowa (Schoumacher and Ackerman 1965)
3=Missouri River, Nebraska (Hesse et al. 1978)
4=Lake Dardanelle, Ark. River, Arkansas (Freeze and Tatum 1977)
5=Powder River and Crazy Women Creek, Wyoming (Smith and Hubert 1988)
6=Des Moines River, Iowa (Harrison 1957)
7=Tongue River, Montana (Elser et al. 1977)

Figure 3. Total length at age for individual channel catfish collected (n=44) in 1991 from the Buffalo River showing the two distinct growth patterns. These two growth patterns were also found for channel catfish collected in 1992.


Total Length (cm)
70
60
50
40
30
20
10
0
Stocked
Natural Reproduction
0
1
2
3
4
5
6
7
8
9
10
11
12
Age

APPENDIX B

PRE-SPAWNING MIGRATION OF CHANNEL CATFISH INTO THE KINGS, MULBERRY, AND BUFFALO RIVERS: EFFECTS OF A COLD TAIL-WATER

ABSTRACT

Spring migration of channel catfish (Ictalurus punctatus) into the Kings, Mulberry and Buffalo rivers, Arkansas, was compared to evaluate if fewer adult catfish migrate into a warm-water tributary that flows into a cold tail-water. The Buffalo River flows into a cold tail-water reach of the White River and supports a sparse channel catfish population compared to similar rivers in the region that do not flow into a cold tail-water. This may be an important factor because an increasing number of studies have demonstrated that channel catfish make pre-spawn migrations into tributary streams and may contribute significantly to tributary populations. To assess channel catfish migration, hoop nets were deployed at the confluence of each river and fished continuously from 29 March to 22 April 1992, with total catches used as an index of the relative number of fish migrating into each river. Movements of channel catfish into each river were observed throughout April; however, the relative number migrating into the Buffalo River (n=33) was significantly less than the Kings (n=169) or Mulberry (n=263) rivers. Water temperature differed significantly between the White and Buffalo rivers during the sampling period, but did not differ between the Kings or Mulberry, and their respective confluence. Although cold White River tail-waters do not totally inhibit overwintering and migration of adult channel catfish into the Buffalo River, reduced inputs from migratory catfish may partially account for the rivers low reproductive output and sparse adult population.

INTRODUCTION

An increasing number of tagging studies have shown that channel catfish (Ictalurus punctatus) exhibit spring migrations from larger rivers or lakes into tributary streams. These spring migrations have been documented for river systems in a wide range of geographical locations. Humphries (1965) reported that channel catfish in the Savanna River, Georgia, made a definite upstream migration into a tributary stream during May and June, followed by downstream movement back into the river during July. In South Dakota, June (1977) reported that channel catfish in Lake Oahe moved into tributary rivers prior to spawning. Movements of channel catfish into or out of tributaries have also been observed for river systems in Florida (Hale et al. 1986), Iowa (Welker 1967), Louisiana (Perry et al. 1985), Missouri (Newcomb 1989; Dames et al. 1989), Wisconsin (Ranthum 1971), and Wyoming-Montana (Smith and Hubert 1989). These movements, as well as migrations of channel catfish reported from other investigations, are believed to be associated with spawning.

Annual migrations of channel catfish appear to be in response to either a lack of overwintering habitat in the tributary (Newcomb 1989) or a lack of suitable spawning habitat or conditions in the confluence system (Gerhardt and Hubert 1990). Channel catfish appear to require substantially different habitat areas for overwintering and spawning. Newcomb (1989) found that deep scour-holes in the Missouri River provide valuable overwintering habitats; during winter, channel catfish were only collected in depths greater than 3.7 m and water velocities less than 0.3 m/s. He reported a general pattern of channel catfish movement from these overwintering habitats into tributaries in spring, summer, and fall. Use of deep-water (4.9 to 7.6 m) habitats by winter aggregations of channel catfish have also been reported for the Mississippi River (Hawkinson and Grunwald 1979). Gerhardt and Hubert (1990) concluded that the more abundant spawning habitat in a Wyoming tributary explained the substantial use by channel catfish during the spawning period. They found that 36% of radio-tagged channel catfish spawned in tributaries, although tributaries made up less than 1% of the total stream-lengths these fish traveled during pre-spawning periods.

Many small rivers may not provide a combination of both suitable spawning habitat and deep overwintering areas for channel catfish (Newcomb 1989; Gerhardt and Hubert 1990). For example, tributary streams may provide important spawning habitat, but may lack suitable overwintering areas. Although the tributary population of channel catfish may depend upon annual inputs from spring migrations of catfish, which overwintered in other waters, information is not available on the importance of these annual migrations for maintaining the tributary population. In the Wisconsin River, it is estimated that greater than 75% of the channel catfish population migrates into overwintering habitats in the upper Mississippi River, and that an absence of migrating adults would result in a significantly reduced catfish population in the Wisconsin River (T. D. Pellett and D. Fago, Wisconsin Department of Natural Resources, unpublished data).

In Arkansas, evaluation of the reproductive output of channel catfish in several warm-water Ozark streams revealed significantly lower abundance of young-of-year (YOY) channel catfish in the Buffalo River relative to similar, nearby, rivers. The Buffalo River was also found to support a sparse population of adult channel catfish, with previously stocked, hatchery-reared catfish making up a significant (>94%) portion of the population. Further analysis of possible reasons for the low reproductive output and recruitment observed in the Buffalo River revealed that one of the most striking differences among the rivers investigated is that the Buffalo River flows into a cold tail-water reach of the White River. These cold tail-waters may contribute to the sparse channel catfish population in the Buffalo River if historic annual inputs of migrating adult catfish stocks have been reduced or eliminated.

Prior to construction of Bull Shoals Reservoir in 1952, the present cold-water reaches of the White River had a historically abundant channel catfish population (Keith 1964). Construction of Bull Shoals Dam, with its hypolimnentic release of cold tail-water, eliminated native warm-water species from cold-water reaches of the river (Hoffman and Kilambi 1971) and may have eliminated historic inputs from migratory stocks of channel catfish into the Buffalo River as well as other tributaries to the White River. In a study of tail-waters in Arkansas, Brown (1967) reported an absence of channel catfish in samples collected from stations on the White River extending 40 km below Bull Shoals Dam, including the confluence with the Buffalo River. He also found no indication of large, spring movements of any species from the White River into the Buffalo River. Water temperature in the White and Buffalo Rivers at their confluence differ by as much as 10.0 and 21.5°C during spring and summer, respectively, but is similar during fall and winter (Brown 1967). Studies on other cold tail-waters have shown that spawning of warm-water fishes is inhibited by release of hypolimnetic waters (Pfitzer 1962; Brown 1967), and that changes in water quality, especially water temperature, seem to be the most likely factors associated with the disruption of natural stream communities (Edwards 1978).

The objective of this study was to determine if the cold tail-water reach of the White River has eliminated pre-spawn migration of channel catfish into the Buffalo River. This was tested by comparing relative numbers of catfish migrating into similar, nearby rivers, which do not flow into a cold tail-water. Knowledge about potential effects of cold tail-water on channel catfish migration will aid in assessing reasons for the low reproductive output and sparse population of catfish observed in the Buffalo River.

STUDY SITES

Pre-spawning migration of channel catfish was assessed for the Kings, Mulberry, and Buffalo rivers of northwestern Arkansas (Figure 1). These three rivers originate in the Boston Mountains and are typical clear-water Ozark streams characterized by long pools separated by short riffles. The substrate is primarily gravel and rubble in the headwater sections; rubble, boulder, and bedrock in the middle reaches; and some deposits of sand and silt in the lower reaches. Land use in the watersheds of the Kings and Mulberry rivers is a combination of agriculture and forestry. The Buffalo River flows through U.S. Forest Service and National Park Service (NPS) lands and has been managed by NPS since 1972. The Kings, Mulberry, and Buffalo rivers are free-flowing upstream from their confluence with Table Rock Reservoir, the Arkansas River, and the White River tail-water below Bull Shoals Dam, respectively (Figure 1).

Table Rock Lake is the second in a series of three large impoundments on the White River. The Kings River flows into Table Rock in the middle portion of the lake near the Missouri border. The Arkansas River is a large river system characterized by was 1.4, 0.1, and < 0.1 for the three rivers, respectively. No previously marked catfish were recaptured on subsequent dates, suggesting upstream movement.

Length distribution of channel catfish collected also differed among rivers. A large proportion of channel catfish moving into the Mulberry River were small, while catfish moving into the Kings and Buffalo Rivers showed a more even size distribution (Figure 3). Unlike the confluences of the Kings and Buffalo rivers, the Arkansas River is open to commercial fishing, thus the larger proportion of small channel catfish moving into the Mulberry River may result from commercial harvest of catfish larger than the 38-cm minimum length limit. Only 12% of channel catfish moving into the Mulberry River exceeded 38 cm compared to 66 and 47% of catfish collected from the Kings and Buffalo rivers, respectively.

Water temperatures observed during the sampling period did not differ ($P > 0.05$) among the Kings, Mulberry, and Buffalo rivers. However, water temperatures differed significantly ($P < 0.05$) between the White and Buffalo rivers, but not between the Kings River and Table Rock Reservoir or between the Mulberry and Arkansas rivers (Table 2). Water temperature among the Mulberry/Arkansas rivers, and Kings River/Table Rock Lake had consistent trends throughout April, while the Buffalo and White rivers had increasingly larger differences (Figure 4). Variation in catch rates of channel catfish during March and April (Figure 3) was not significantly ($r^2 > 0.80$) correlated with water temperature within any of the three rivers.

DISCUSSION

Although several factors can influence catch per unit effort results (Ricker 1975) and hoop net catches (Muncy 1957; Mayhew 1973; Hubert and Schmitt 1982), comparative catches of channel catfish in the present study were believed to be reliable because of similar limnological and climatic conditions among the Kings, Mulberry, and Buffalo rivers during the sampling period, and because of the restricted channel widths of these tributaries. Muncy (1958) and others have shown that adult channel catfish are highly susceptible to capture in hoop nets during the spawning season; Smith and Hubert (1989) concluded that seasonal trends in hoop net catches within a great plains river system were associated with spawning migrations into tributary creeks. Similar to proportional relationships established between catch per unit effort and fish stock abundance (Ricker 1940), CPUE for hoop net samples in this study represent the proportional abundance of channel catfish migrating into each tributary. Thus, despite the shortened sampling interval due to high water, spring hoop net sampling measured the relative number of channel catfish migrating into the Kings, Mulberry, and Buffalo rivers, with the assumption that catfish collected at the mouth of each tributary were migrating into the river; this assumption was supported by an absence of recaptures. In addition, a number of marked catfish were recaptured 50 to 60 km up-stream later in the summer.

The appearance of channel catfish moving into the Kings, Mulberry, and Buffalo rivers conforms with similar patterns of spring movements reported for other waters (e.g., Humphries 1965; June 1977; Smith and Hubert 1989). However, the number of channel catfish migrating into the Buffalo River was significantly less than was observed in the Kings or Mulberry rivers, although the measured physical characteristics (water temperature, turbidity, total discharge) did not significantly vary among these tributaries. Brown (1967) also reported a lack of large, spring movements of channel catfish into the Buffalo River. Previous investigation documented that YOY abundance of channel catfish was also significantly lower in the Buffalo River compared to the Kings and Mulberry rivers, and that the Buffalo River supports a sparse adult population consisting of a large proportion (> 94%) of previously stocked fish. This suggests that reduced inputs from migratory stocks of channel catfish since completion of Bull Shoals Dam in 1952 may at least partially account for the lower reproductive output and sparse adult population observed in the Buffalo River. In the Wisconsin River, it has also been suggested that without annual migrations of channel catfish, the population in the river would be sparse (T. D. Pellett and D. Fago, Wisconsin Department of Natural Resources, unpublished data).

The relatively small number of channel catfish migrating into the Buffalo River appears to be mainly due to the presence of cold White River tail-waters, which had significantly lower mean temperature than the Buffalo River during the sampling period. Hoffman and Kilambi (1971) investigated the environmental changes produced by these cold tail-waters and concluded that temperature differences between the White and Buffalo rivers had the largest influence on presence and abundance of various fish species. Cold tail-waters have eliminated the historic channel catfish population from this section of the White River (Brown 1967) and may have eliminated possible temperature cues needed for spring migration. In contrast, no apparent barriers to migration exist downstream from the Kings or Mulberry rivers, thus, channel catfish are able to move freely between these rivers and their respective confluence.

Cold tail-waters also appear to have eliminated historic distributions of white bass (Morone chrysops) in the Buffalo River drainage (Robison and Buchanan 1988). Recent fish surveys (Brown 1967; Cashner and Brown 1977) have not documented white bass migrations into the Buffalo River since construction of Bull Shoals Dam. In this study, spring migrations of white bass were observed from hoop net catches in the Kings and Mulberry rivers, but not in the Buffalo River (Table 3). Similar to channel catfish, white bass are known to exhibit extensive spring migrations into smaller tributaries prior to spawning (Robison and Buchanan 1988), but cold tail-waters may inhibit these migrations.

Cold tail-waters of the White River may act as a barrier to channel catfish migration similar to that reported from other studies. For example, McCammon and LaFaunce (1961) suggested that the relatively closed population of channel catfish in the Sacramento River, California was the result of a cold tail-water which inhibited movement up-river; increased salinity inhibited down-river movement, and the presence of a diversion dam prevented migration into a major tributary. Similarly, Welker (1967) reported that a low-head dam appeared to inhibit up-stream movement of channel catfish in the Little Sioux River, Iowa, and McCammon (1956) found that the Palo Verde Weir on the lower Colorado River acted as a barrier to upstream movement of channel catfish because a number of tagged fish were caught at the base of the weir and few, if any, catfish move upstream across the barrier. In contrast, Hubley (1963) found that 24% of all tagged channel catfish recaptured (n=497) passed through one or more lock and dam(s) on the upper Mississippi River.

Newcomb (1989) recognized the importance of excluding structures that hinder channel catfish passage to important seasonal habitat areas in the Missouri River and its tributaries. Sparse populations of channel catfish observed in some waters may be due to restrictions on catfish migration if suitable habitat for both spawning and overwintering is not available. The need for these specific habitat areas is illustrated by the extensive upstream or downstream movements documented from channel catfish tagging studies. Although clear-water Ozark streams such as the Kings, Mulberry, and Buffalo rivers have abundant spawning habitat such as large boulders and rock crevasses, suitable overwintering areas appear to be more limited because there are relatively few deep pools (> 5 m) in these rivers, especially in downstream reaches. Results from this study suggest that the sparse population of channel catfish in the Buffalo River may be partially attributed to reduced inputs from historic migratory stocks due to the presence of cold White River tail-waters. However, additional research is needed to quantify the importance of annual pre-spawning migrations for maintaining a tributary population.

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Table 1. Comparison of mean (±SD) catch/hoop net-set of channel catfish migrating into the Kings, Mulberry, and Buffalo rivers. Values in each row without a letter in common are significantly different ($P < 0.05$).[a]

	River		
Variable	Buffalo	Kings	Mulberry
Mean catch/net-set	3.3	16.9	26.3
	±6.4	±19.2	±36.0
Transformed $\ln(x + 1)$ mean catch/net-set	0.8^{y}	2.2^{z}	2.2^{z}
	±1.1	±1.3	±1.8

[a] Comparisons were not made between mean catch/net-set due to violations of statistical assumptions (unequal variance among rivers).

Table 2. Comparison of mean (±SD) water temperature (°C) among the three rivers and their confluence.

River	Confluence	P-Value
Kings	Table Rock Lake	
13.9 (±4.0)	14.3 (±4.1)	$P > 0.05$
Mulberry	Arkansas River	
13.6 (±4.1)	15.5 (±4.0)	$P > 0.05$
Buffalo	White River	
14.8 (±3.6)	9.9 (±1.6)	$P < 0.05$

Table 3. Total number of various species captured in hoop net samples from the mouth of the Kings, Mulberry, and Buffalo rivers from 28 March to 22 April. Total number of recaptures for each species are in parentheses.

Species	River: Kings	River: Mulberry	River: Buffalo
black crappi	—	36 (1)	1
bluegill	174 (4)	155 (9)	—
channel catfish	169	263	33
flathead catfish	5	3	14 (1)
freshwater drum	—	1	—
largemouth bass	—	5 (1)	—
longear sunfish	18 (1)	9	182 (21)
Ozark bass	—	—	70 (6)
redear sunfish	21 (2)	—	—
redhorse sp.	25	—	9
smallmouth bass	—	—	24 (1)
smallmouth buffalo	—	3	—
walleye	1	—	—
warmouth	8	1	—
white bass	40 (1)	30 (2)	—
white crappi	—	1	—
Total species	9	11	7

Figure 1. Study sites at the mouth of the Kings, Mulberry, and Buffalo rivers of northwestern Arkansas.

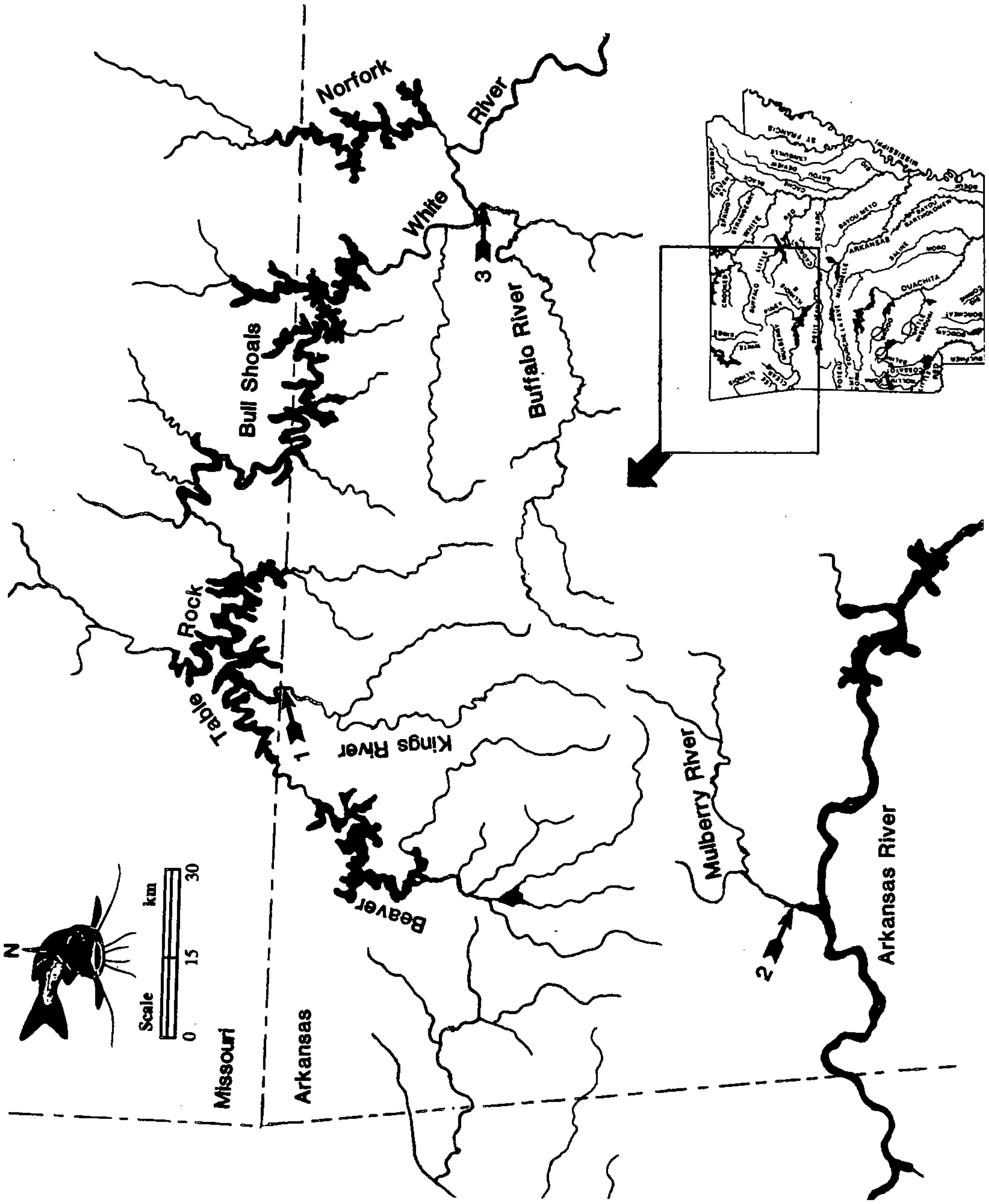
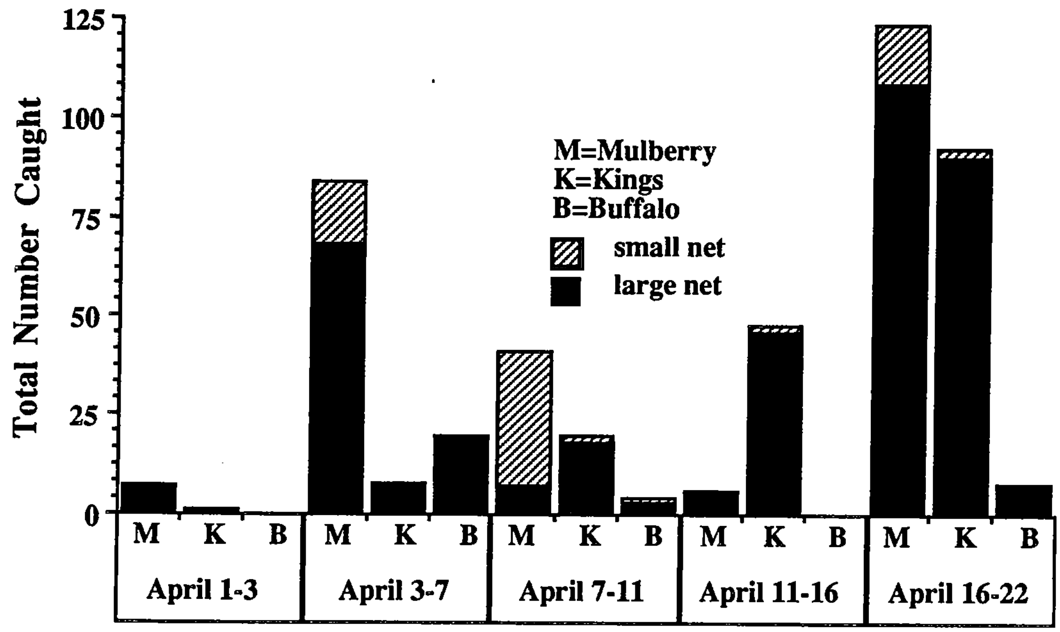

Norfork
White
River
Bull Shoals
Buffalo River
Table Rock
Kings River
Beaver
Mulberry River
Arkansas River
Missouri
Arkansas
Scale
km
0
15
30
N
1
2
3

Figure 2. Temporal variation of channel catfish caught in large and small hoop nets for the Kings, Mulberry, and Buffalo rivers.



125
100
75
50
25
0
Total Number Caught
M=Mulberry
K=Kings
B=Buffalo
small net
large net
M K B
April 1-3
M K B
April 3-7
M K B
April 7-11
M K B
April 11-16
M K B
April 16-22

Figure 3. Length distribution of channel catfish migrating into the Kings, Mulberry, and Buffalo rivers.

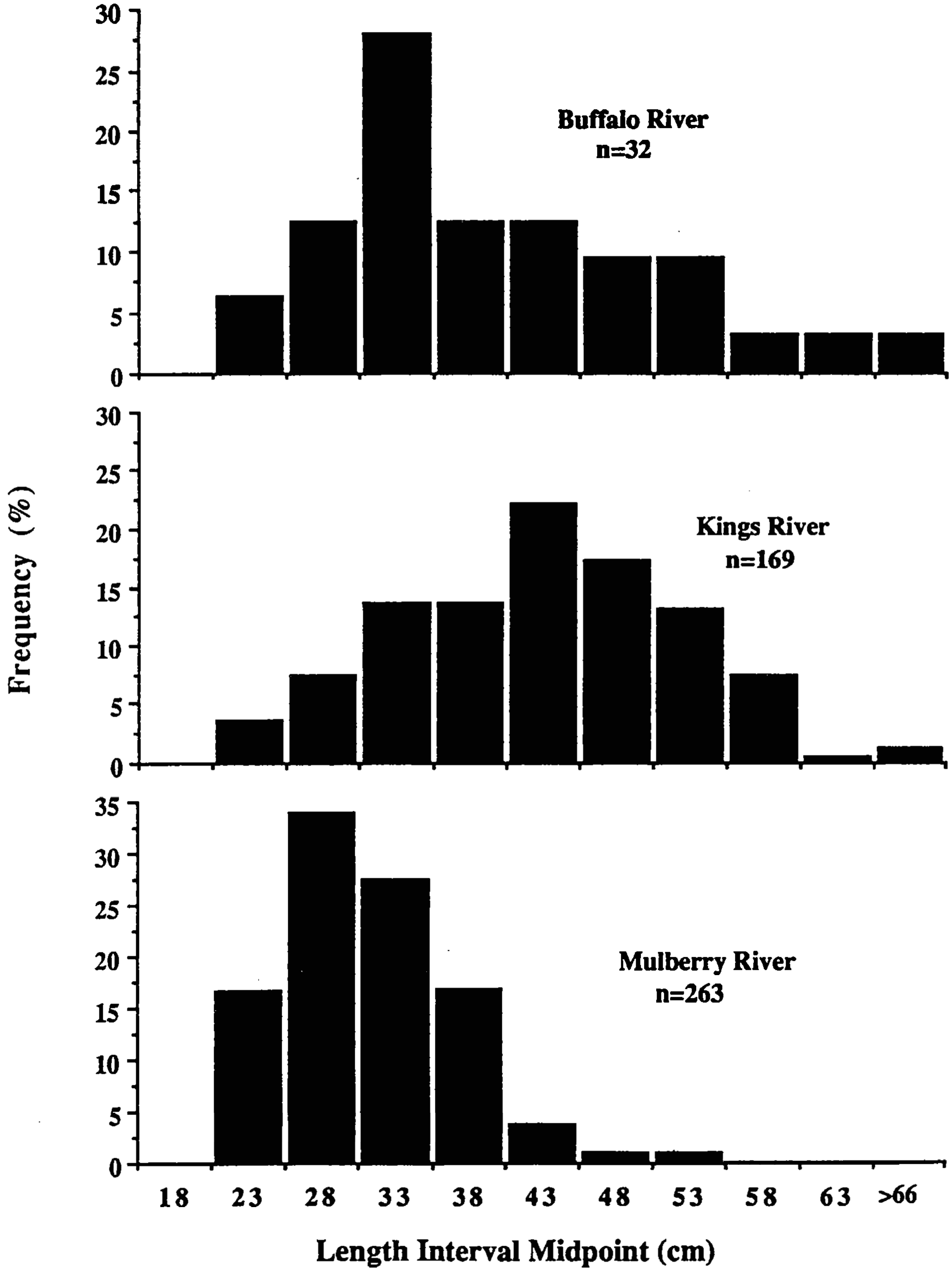
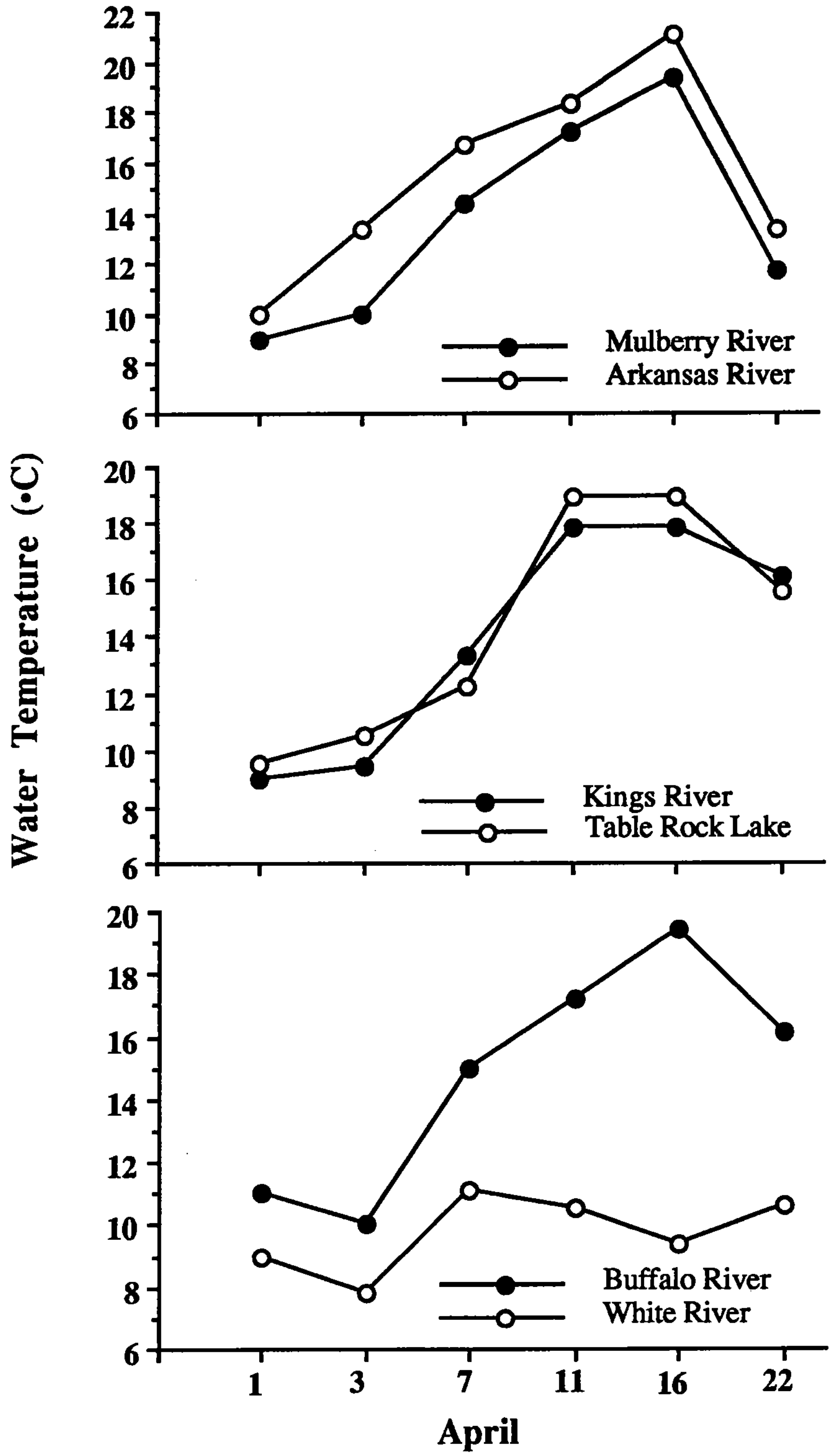

Frequency (%)
Buffalo River
n=32
Kings River
n=169
Mulberry River
n=263
0
5
10
15
20
25
30
35
18
23
28
33
38
43
48
53
58
63
>66
Length Interval Midpoint (cm)

Figure 4. Water temperatures for the Kings, Mulberry, and Buffalo rivers, and their respective confluence.


22
20
18
16
14
12
10
8
6
Mulberry River
Arkansas River
20
18
16
14
12
10
8
6
Kings River
Table Rock Lake
20
18
16
14
12
10
8
6
Buffalo River
White River
1
3
7
11
16
22
April
Water Temperature (•C)